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Vol. II JANUARY 1961 No. I

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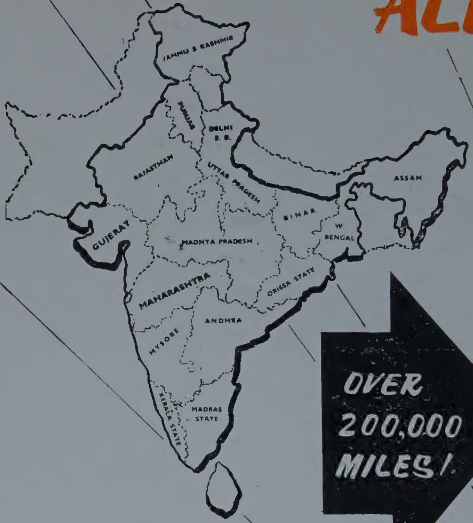

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POWER ENGINEER

Vol. II JANUARY 1961 No. I

CONTENTS

		PAGE
HIGHLIGHTS		A5
EDITORIAL — CHAMBAL VALLEY PROJECT		1
INTEGRATED OPERATION OF HYDRO AND THERMAL STATIONS IN INDIA	*K. P. S. Nair*	2
CHAMBAL POWER GRID	*K. S. Sivaprakasam*	8
ELECTRICAL PROTECTION OF LARGE HYDRO-ELECTRIC GENERATORS	*O. D. Thapar*	12
ELECTRICAL CLEARANCES IN OUTDOOR HIGH VOLTAGE SUBSTATIONS	*H. R. Kulkarni*	18
SOME OBSERVATIONS REGARDING THUNDERSTORMS AND LIGHTNING SURGES ON TRANSMISSION LINES	*S. Szafranski*	26
CONFERENCE OF ELECTRICAL INSPECTORS		36
PROGRESS OF POWER PROJECTS		38
ELECTRICITY STATISTICS		39
ENGINEERING NOTES		40
NEWS OF CURRENT INTEREST		42
BOOK REVIEWS		45
SOCIETY ACTIVITIES		46
PERSONAL NOTES		52
INDEX TO ADVERTISERS		A47

Statements and opinions given in the articles appearing in POWER ENGINEER are expressions of contributors, for which the Society assumes no responsibility.

COVER PICTURE — A view of the Gandhisagar Dam showing the power house and the substation (*see pp.* 8-11).

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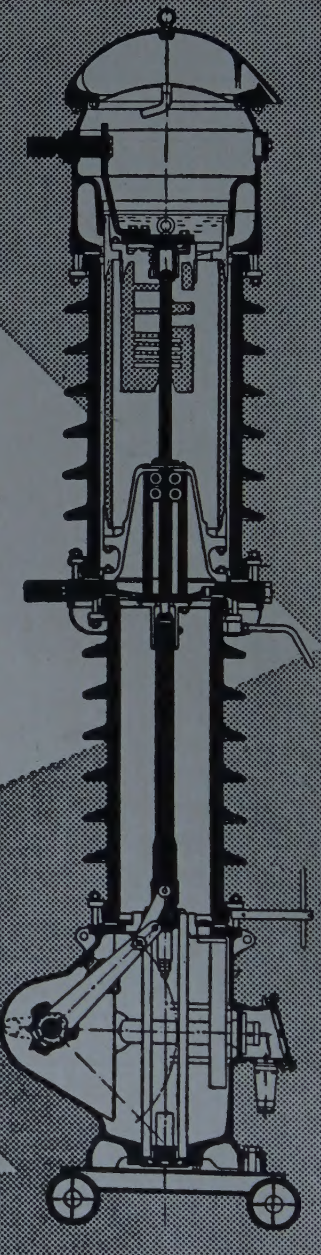

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HIGHLIGHTS

Integrated Operation of Hydro and Thermal Stations in India — In this paper the author has discussed the importance of hydro power stations on a long-range basis for co-ordinated operation in a system which includes thermal generation. For deriving maximum benefits in the way of increased firm capacity, it is necessary to incorporate the facilities for integrated operation in the design of hydro stations from the beginning. After discussing several possible hydro-thermal combinations, the author has concluded that for the most economic operation thermal plant capacity should be run as system base load stations with the hydro-electric stations being assigned the low load factor operations on the peaks of system load.

Chambal Power Grid — With the recent commissioning of the Gandhisagar station in November 1960, the first stage of the power development in the Chambal valley gets completed. This article gives the broad details of the Chambal transmission system and the machinery and equipment of Gandhisagar power station. Due to the rapid growth of power demand in the Madhya Bharat-Rajasthan region, the importance of expediting work on the second stage, namely the Ranapratapsagar power station, has also been stressed.

Electrical Protection of Large Hydro-electric Generators — In this paper, the author has reviewed the common type of faults which may affect hydro-electric generators and gives the features of the various schemes which are adopted for protection of such generators.

Electrical Clearances in Outdoor High Voltage Substations — In this article the author has reviewed the current practice in the selection of electrical clearances in high voltage substations. For speed of execution and economy in cost of structure and also space requirements, the author has recommended standardization of clearances with lower values for phase to phase and safety clearances than those that are currently in practice.

Some Observations Regarding Thunderstorms and Lightning Surges on Transmission Lines—Thunderstorms and lightning are the major causes of outages in transmission lines. In this paper the author has explained the formation of cloud, electric charge and the discharge of the same as lightning strokes and has discussed the factors affecting the lightning response of overhead lines such as waveform and magnitude of lightning current and voltage of the lines. Details of various methods of calculation of lightning surge voltage and the instruments used for recording the same have also been given.

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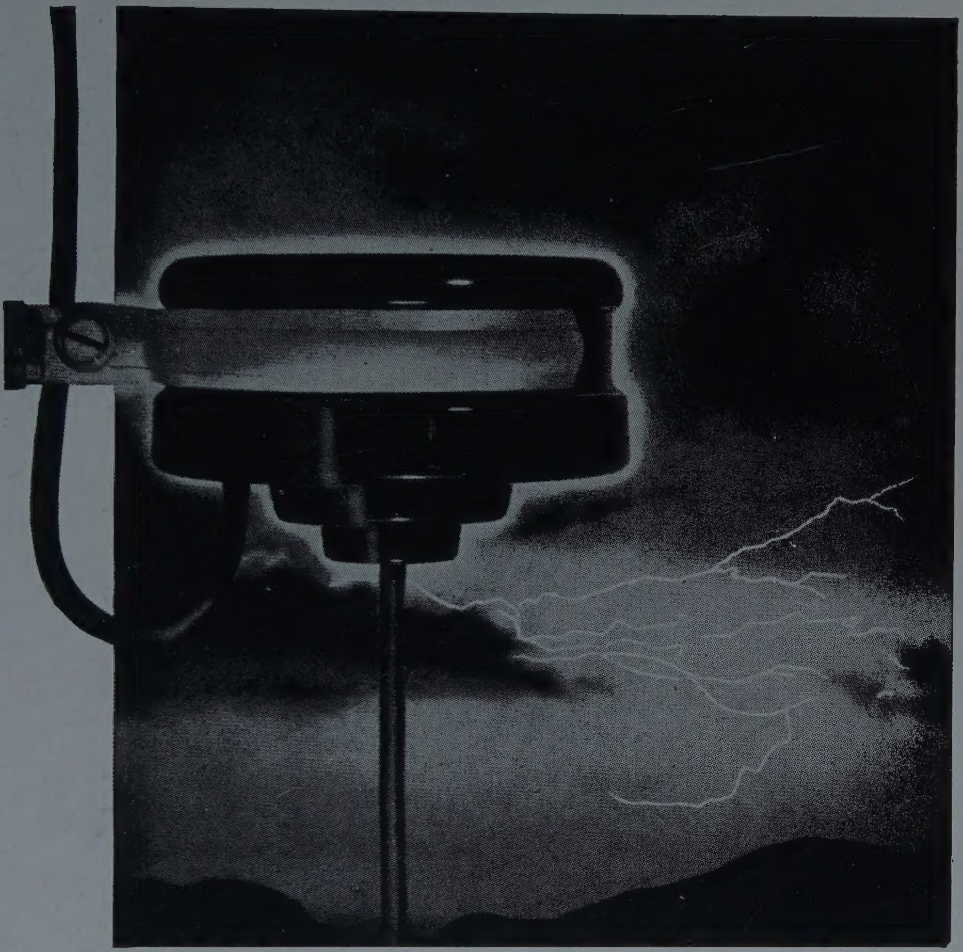

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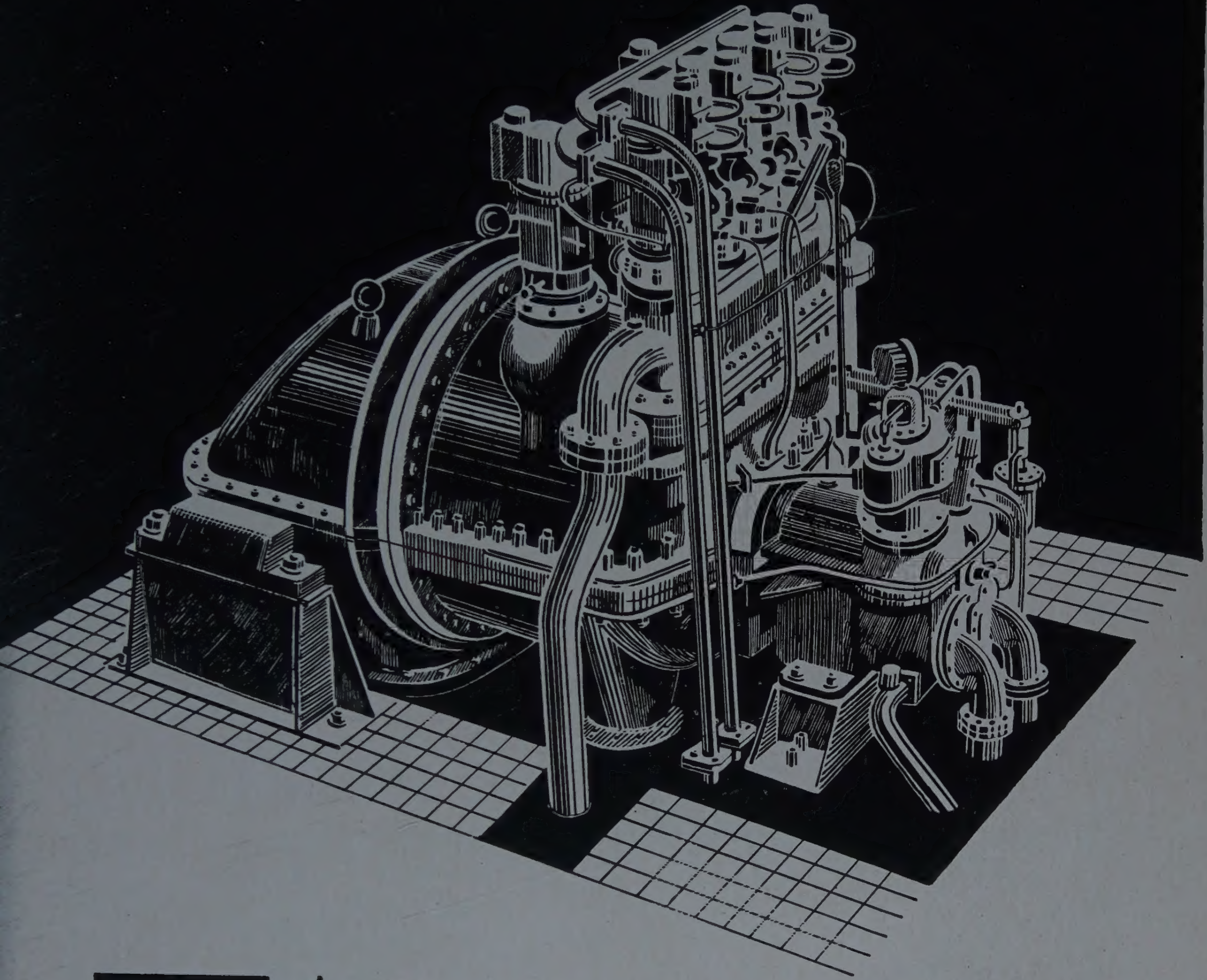

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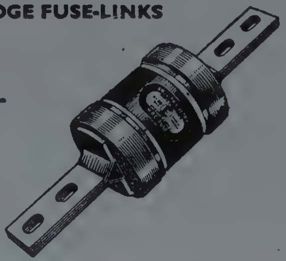

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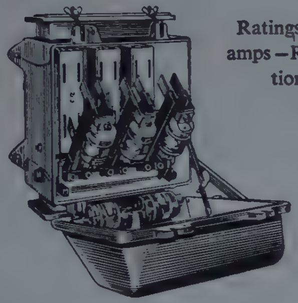

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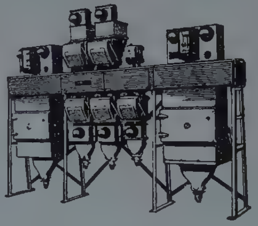

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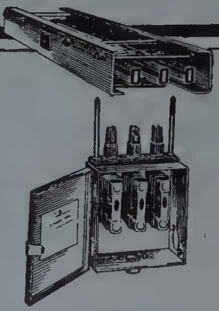

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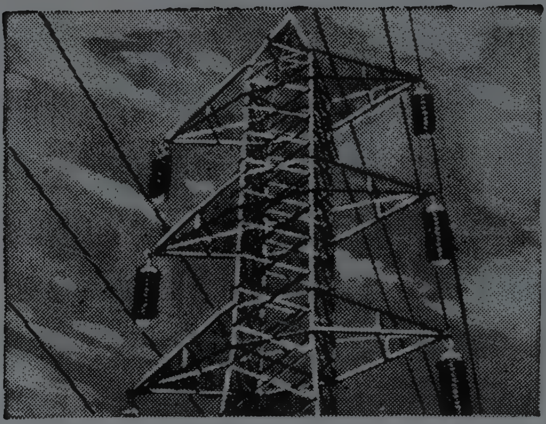

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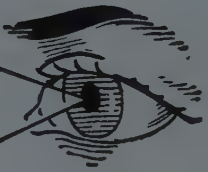

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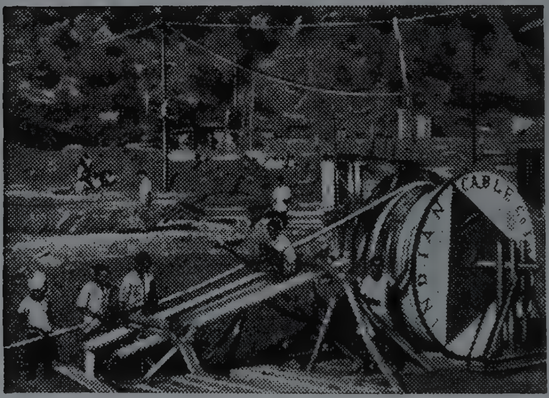

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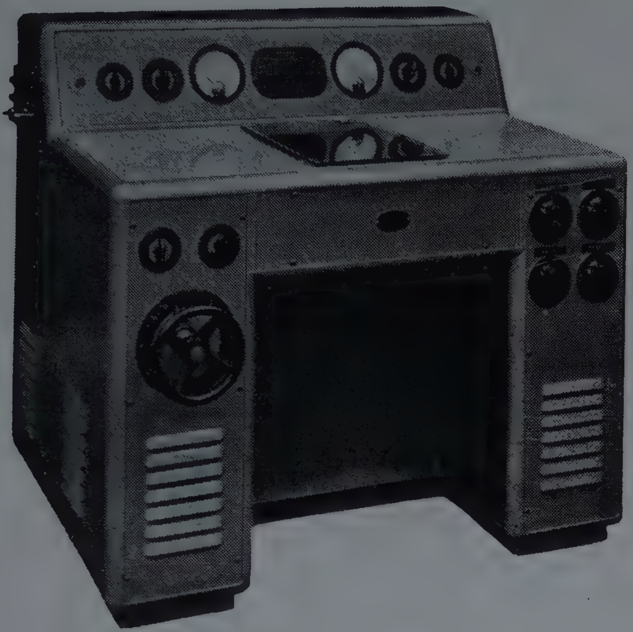

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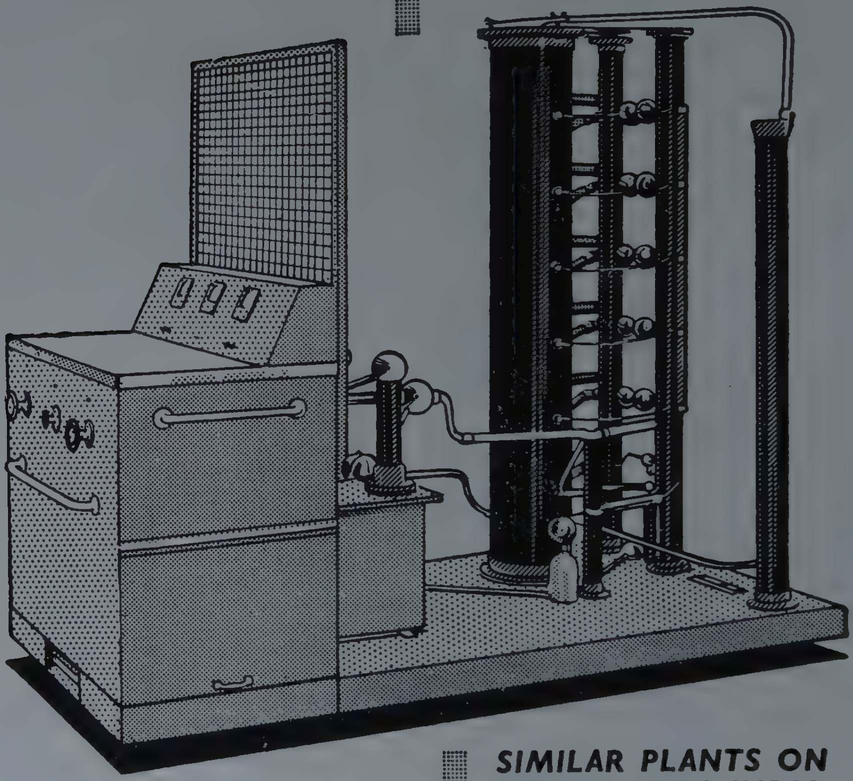

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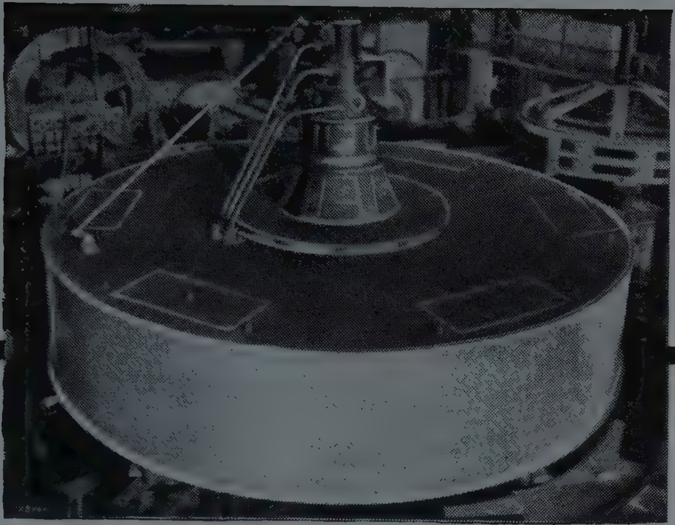

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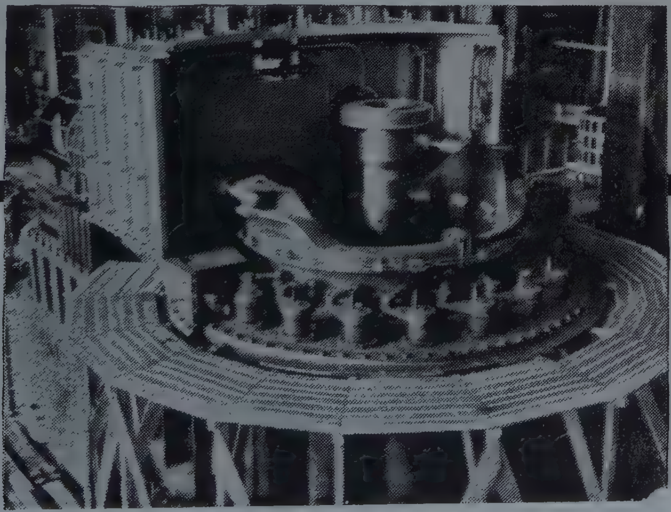

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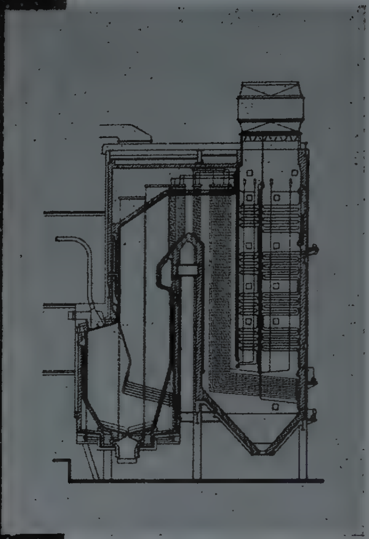

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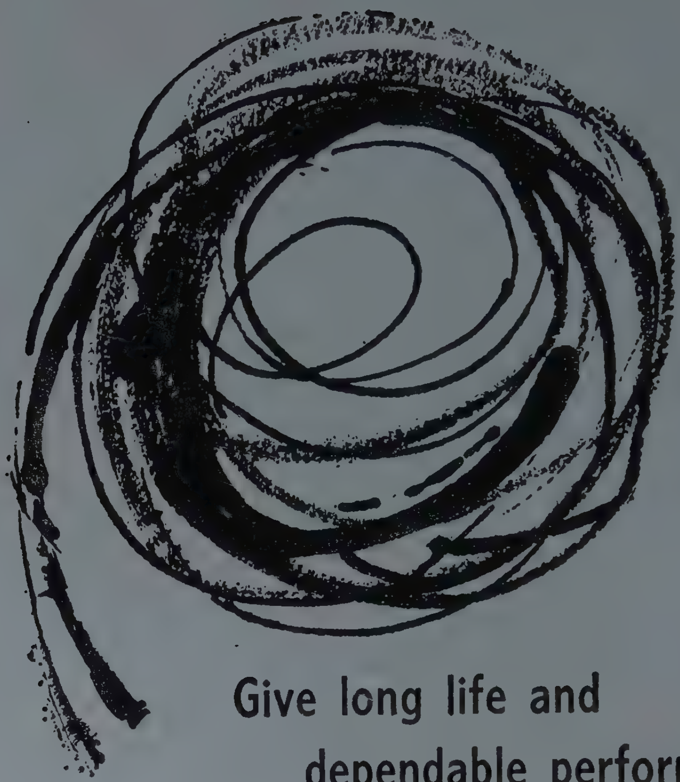

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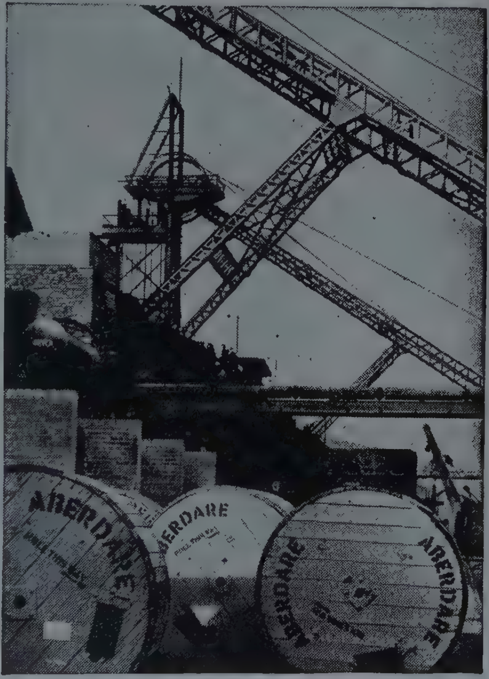

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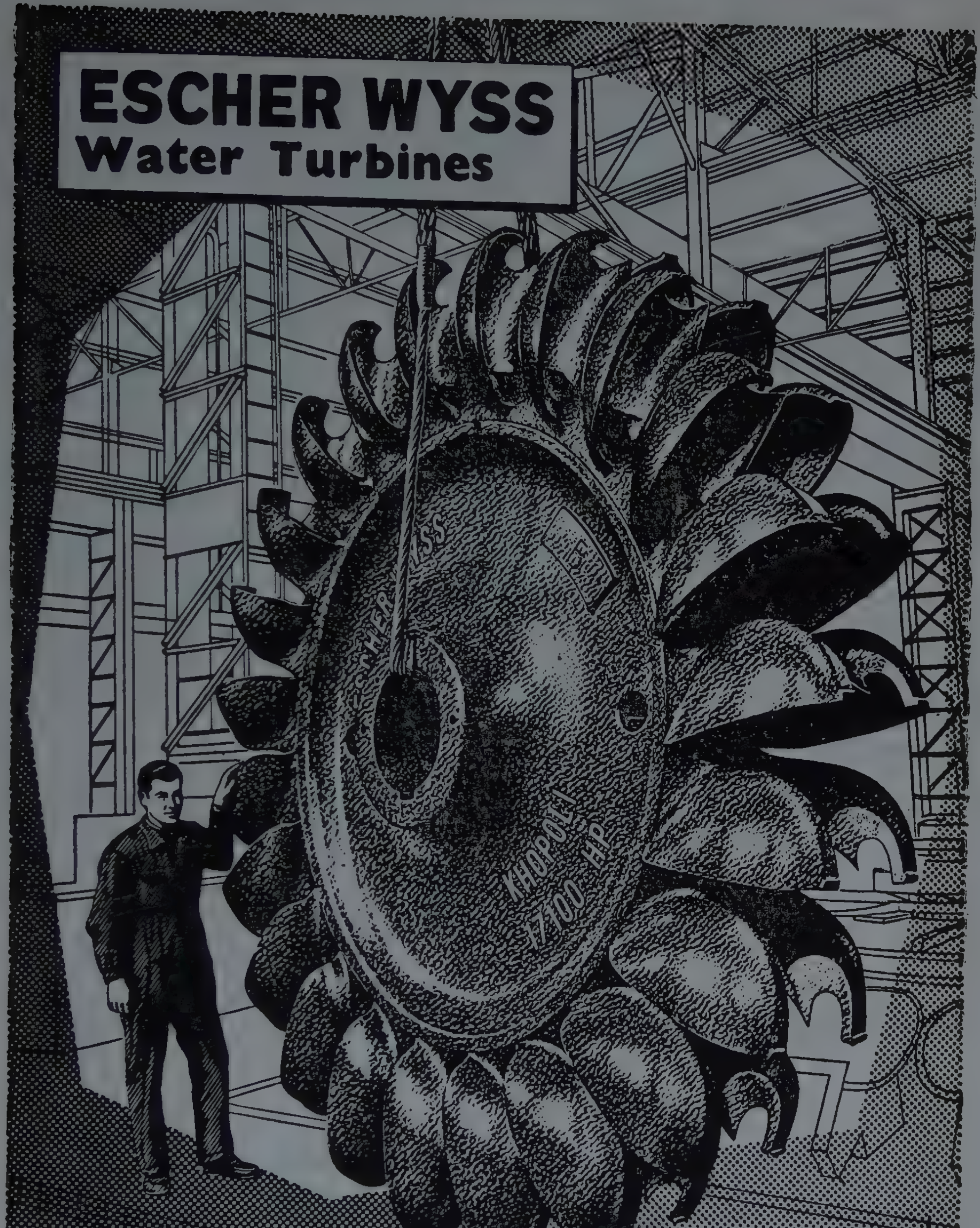

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Chambal Valley Project

THE completion of the first stage works of the Chambal project comprising the Gandhisagar dam and power house in November 1960 marks a notable achievement in the irrigation and power programme of the second five-year plan. In fact, it is a landmark in the history of Madhya Pradesh and Rajasthan States being the first large project to be undertaken and completed. The benefits of the scheme would spread over extensive areas in both the states both for irrigation and for supply of power to industry and home.

The Chambal valley project is an integrated development and on full completion will give a generation of 232,000 kW of firm power at 60 per cent load factor and an irrigation capability of about 565,000 hectares (1·4 million acres). The present installed capacity at the Gandhisagar power station consists of 92,000 kW only and it will be raised to 115,000 kW in due course. The remaining power generation would be done at the Kotah and Ranapratapsagar dams, work on which is now in progress.

Although larger schemes have been completed or are in progress in various other parts of India, the Chambal project is unique as it provides a good example of successful inter-state co-operation in the development of a common river valley. The experience gained in the management and construction of this project would be of immense value for undertaking many more inter-state schemes which would be initiated during the third and subsequent plans. The common problems confronting inter-state schemes are (1) unified control, (2) sharing of benefits, (3) sharing of costs, (4) compensation to and resettlement of people from submerged areas, etc. In the case of the Chambal project, a Control Board was established at the very outset invested with full powers for taking policy decisions which, by convention, the two State Governments agreed to implement without questioning. Subsequent experience has shown that this method of working has been extremely satisfactory and has led to the successful completion of this scheme.

While we are naturally happy at the completion of more and more power schemes, it is of utmost importance that the lessons learnt from each one should be carried forward in our further work. When we compare such aspects like ability to design, speed of construction, efficiency of work and training of technical personnel with the standards obtaining in advanced countries, we cannot afford to be complacent about our achievements. We have to make a great headway in these directions which are of utmost importance to our future progress if we are to realize the big targets set for the third plan. Furthermore, we should not allow narrow parochial views to bear on problems of resources development, which should be considered from a broad national angle. We do hope that both the engineers and administrators would concentrate on improving the methods of design, construction and management, which would lead to better economy and efficiency.

Integrated Operation of Hydro and Thermal Stations in India

by **K. P. S. NAIR**

INTEGRATED operation of hydro and thermal stations is a well-established practice all the world over. The limited scope of such combinations in India in the past—the only major system actually planned on the basis of hydro-thermal co-ordination being that of the D.V.C.— has been mainly due to the fact that there are few regions in the country with an abundance of both resources capable of easy development. The relatively small power stations, hydro and thermal, which were required to meet the small demands for power therefore sprang up largely independent of each other. Recent rapid increases in the demands for power have completely altered the picture. A number of hydro projects, e.g. Bhimkund in Orissa, Koel-Karo in Bihar, Sileru in Andhra, Purasa in Madhya Pradesh, etc., are being planned in regions where there is abundance of coal and major thermal installations have been and are being planned in areas like Bombay, Ahmedabad and Delhi which are quite far from the main collieries. Further, the outlying coalfields of India in Madhya Pradesh, Andhra, Madras, etc., are being rapidly developed to reduce the burdens on transport of coal. The advent of nuclear power reactors, which open up possibilities of large-scale thermal generation even in regions far remote from the collieries, is another significant development which would considerably enlarge the scope of hydro-thermal combinations in the future. Large programmes of power plant expansions naturally require considerable investments both in capital and foreign exchange. Co-ordinated operation of hydro and thermal stations affords prospects of deriving maximum economic benefits from given investments on power generation and it therefore assumes vital importance in planning for future power development.

Main Types of Co-ordination

Hydro-thermal combinations may be viewed under two classifications. The first and frequently emphasized aspect relates to the function of thermal stations as 'back-up' to the hydro plants. As the term 'back-up' implies, such thermal plants are retained in the system and commissioned whenever the prime source, i.e. hydro power, fails, as during periods of draught. This aspect needs critical examination since it involves duplication of plant capacity. Hydro schemes in India, being greatly influenced by the seasonal variations in stream flow and by the strength of the monsoons in different years, are examined on the basis of the possible regulation of river flow. Thermal stations, acting as 'back-up' to hydro plants, have also logically to be examined against this background.

In the case of hydro schemes wherever storages provided are large enough to permit almost complete regulation of river flow, evening or both *annual and seasonal* fluctuations — as under Sharavati, Pamba, Idikki, Koyna and other schemes — almost the entire average run-off of the catchment can be utilized to generate firm power at the load factor assigned to the plant. Obviously, such hydro schemes require no thermal 'back-up' at all, since the hydro output is maintained constant practically all the time.

In cases where storages are limited, sufficient, say, only to even out the *seasonal* variations in stream flow, the *firm* power potentials of such hydro schemes should be assessed corresponding to the run-offs of dry years with an availability of about 95 per cent of the time. In all other years except the dry years, such schemes would be capable of considerable additional secondary power generation. 'Back-up' thermal stations

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conceivably be utilized in such cases to improve the commercial utilization of hydro energy, but it must be recognized that the investments on these thermal stations would be kept idle most of time and this would be scarcely justifiable in the context of our financial limitations and the large foreign exchange requirements of thermal stations.

There are other situations where the effective storage is inadequate even for seasonal regulation, either due to topographical limitations or to over-riding claims of flood control and irrigation on the available storage. The D.V.C. and Mettur projects are typical examples of this sort. Here, practically the entire hydro output is seasonal in character and can be commercially exploited only in conjuction with 'back-up' station. Even in such cases, thermal 'back-up' need be resorted to only if the generation patterns of other hydro stations forming the grid cannot be readjusted to afford hydro support. For example, on a close study it has been found that the outputs of the Nilgiri group of hydro stations of the Madras grid — Pykara-Moyar and Kundah — can be so readjusted that they are concentrated largely during the non-irrigation periods, thus firming up the entire seasonal outputs of irrigation-controlled hydro schemes — Mettur, Papanasam and Periyar. The advantage of hydro 'back-up' lies in the fact that the alternative requires only relatively small incremental capital investments on storages, water conductor and plant capacities, and has far lower maintenance costs compared to the alternative of thermal 'back-up'.

It would therefore be seen that, by and large, the use of thermal stations as 'back-up' to hydro schemes in India does not afford economic benefits commensurate with the investment and foreign exchange required.

The second class of hydro-thermal combinations, far more economically justifiable, aims at full utilization of both hydro and thermal resources, all the time, by running thermal stations at their maximum possible capacity and energy values, i.e. at system base loads, the hydro stations being assigned to low load factor operation on the peaks of the system load curve. In fact, the main economic advantages of hydro-thermal co-ordination stem from the basic capacity of hydro stations to run economically at individual load factors very much lower than the normal system load factor.

The benefits are twofold, namely (a) an increase in the firm system capacity beyond the aggregate firm capacities of the stations when run in an isolated manner, and (b) overall economy in energy generation through operation of thermal stations at high load factors and also use of secondary hydro power for reducing fuel bills during years of good rainfall.

There are also a variety of less tangible but none the less important benefits such as savings in standby reserves, greater flexibility in operation while meeting fluctuating demands for power, reductions in requirements of spinning reserves, mitigation of the effects of shortages of hydro power in years of freak rainfall, etc. It must, however, be noted that all these benefits are not necessarily a result of hydro-thermal co-ordination as such. Some of them, e.g. reduction in total standby capacity, follow from interconnected operation of a large number of stations which could be of either type, whereas the others, e.g. flexibility of operation, reduction of spinning and other reserves, are inherent advantages of hydro schemes which are automatically conferred to the system.

Need for Forward Planning of Hydro Schemes

While some of the above benefits would, no doubt, accrue from interconnection of existing hydro and thermal stations which have been planned on the basis of isolated operation, it has to be emphasized that the main economic benefit — namely of increased system firm capacity — can be derived only if the various hydro plants forming the system have been specifically designed for such co-ordinated operation. An example would illustrate the point.

The Tata group of hydro stations of Maharashtra State, when constructed in the early part of the century, were designed to meet their own base and peak demands. The recent introduction into the Bombay grid of a large block of thermal generation at Trombay and Chola during the last decade only increased the effective system capacity corresponding to the thermal capacity additions. To secure the main economic advantage of increased system firm capacity by fully integrated operation of these hydro and

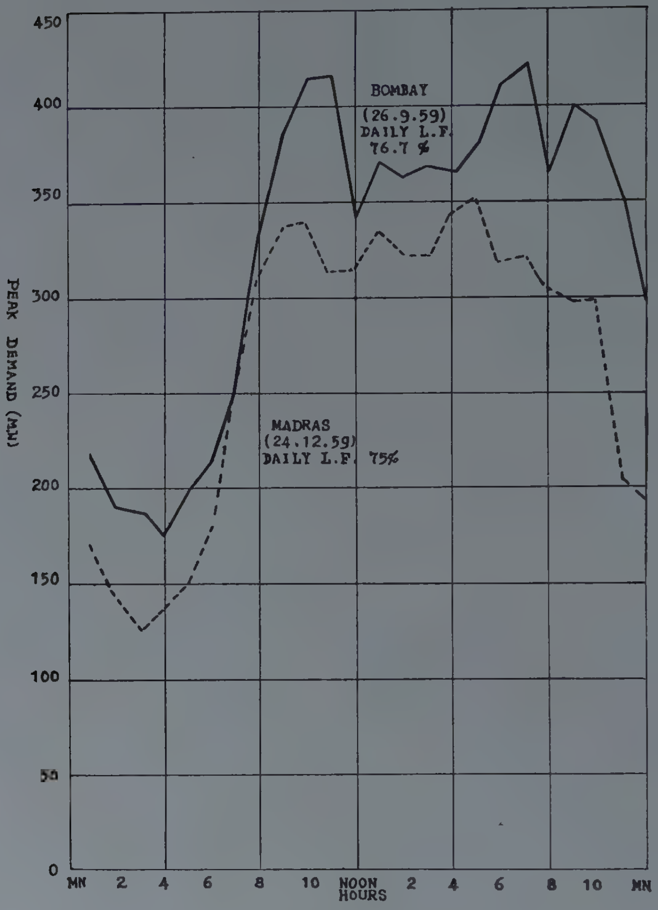

Fig. 1 — Typical daily load curves

thermal stations, increases in the capacities of the water conductor systems and power stations were necessary and this is now being incorporated, to some extent, under the modifications to the Bhira scheme, where a portion of the existing water conductor system is currently under replacement.

It is hardly necessary to point out that unless the required facilities for interconnected operation are incorporated in the original designs of the hydro-electric schemes, subsequent modifications would not only be very expensive but wellnigh impossible. It is this aspect which is, therefore, most important and needs careful consideration since it would vitally influence the designs of all hydro schemes and even affect the choice of schemes for implementation.

Daily Load Curves — Basis for Planning Plant Capacities for Integrated Operation

A thorough study of the daily variations in the demand for power forms the essential background for further examination of the problem. In countries, where there are major variations in the peak demands in different seasons of the year, annual variations are also equally important. In this country, the influence of climatic variations on the aggregate demand for power of large regions is much less pronounced, the changes reflecting mainly the continuous increase in demand due to organic growth of the system. For the present, therefore, studies of daily load curves would be sufficiently illustrative.

The daily variations in the demand for electricity follow the habits and economic life of the community. Numerous patterns of variation are therefore possible and these are themselves liable to change from time to time. Such differences are, in fact, discernible in the demand patterns on power stations supplying isolated communities. But as these power stations grow in size and are interconnected with one another through region-wide grids, the integrated demand pattern tends to become more or less stabilized. In India, the examples of fairly well-developed electricity systems of Maharashtra and Madras bear this out. The former represents an urban system with a great concentration of demand in and around the city of Bombay, whereas the latter represents a vast statewise network, where the sources of power generation are far flung, with very diverse characteristics, and the centres of power consumption are also widely dispersed all over the state. Nevertheless, the integrated load curves of the two systems (FIG. 1) show a striking similarity in spite of their basically different composition. Both these systems have, in the past, been experiencing serious shortages in power and the comparatively high daily load factor of the order of 75 per cent is no doubt a reflection of the severe restrictions imposed on growth. If supply of electricity is made freely available, the trend would be towards sharper peaks and a reduced system daily load factors as experienced in the advanced countries of the world. In future, now that regional grids are being actively planned, it is these integrated daily demand patterns over the entire region which are relevant for planning.

It must be admitted that the above inferences, though quite logical, have been derived from a study of the limited data readily available in the Central Water & Power Commission. The subject is of sufficient importance to warrant a very detailed examination and this should be undertaken by all Electricity Boards and other authorities.

Assuming for the present that future integrated demand patterns of very large regional system would follow the established trends, the plant and energy requirements of hydro stations can be derived directly from the unit curve shown in Fig. 2. The ordinates of these curves represent peak demand (kW) expressed as a percentage of the maximum, whereas the abscissae represent the corresponding energy content expressed as a percentage of the total daily energy requirement. The close identity of the two curves in Fig. 2, prepared for the recent daily curves of Maharashtra and Madras systems, reflect the geometrical similarity of the two system load curves. These curves can be utilized to roughly assess the order of future plant capacity requirements of hydro stations.

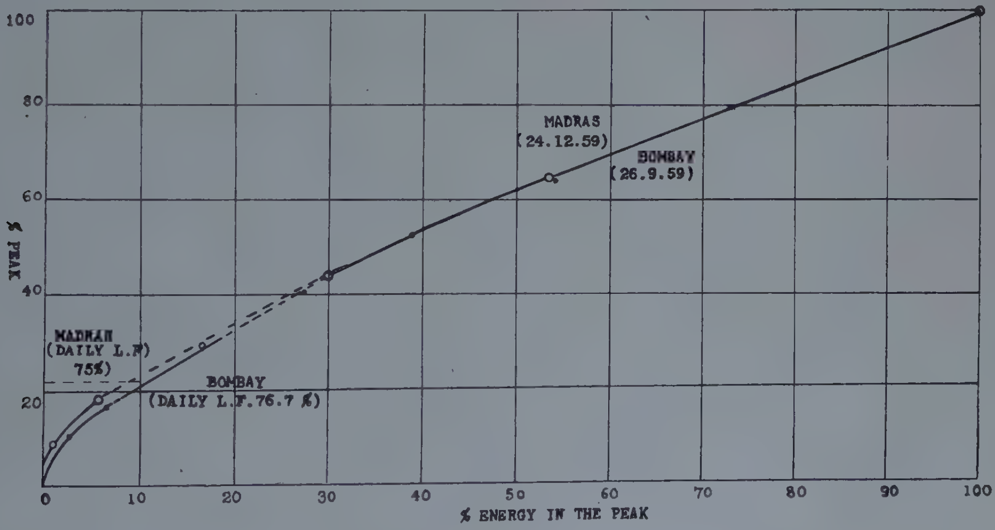

FIG. 2 — CURVE OF PERCENTAGE PEAK AND CORRESPONDING ENERGY

Thus, if a system peak demand of 1200 MW is postulated (the daily energy requirement at 75 per cent I.F. corresponding to 900 MW continuous), it would be seen from the curve that a hydro scheme with a firm (daily) energy potential corresponding to 90 MW continuous (i.e. 10 per cent of the total) can take a peak demand of 264 MW (22 per cent of the system peak). In view of the usefulness of the method and its simplicity, it is suggested that a systematic and thorough statistical study of demand patterns of the large regional power systems of the country should be made to see whether a generally representative unit curve or a set of unit curves can be evolved.

In this context, it is interesting to study the prospects of co-ordinated operation of a hydro and thermal station of the Bombay-Poona grid of Maharashtra, on completion of the second stage of Koyna project (addition of 300 MW) and the proposed Tarapore nuclear station (300 MW). The plant capacities, and *daily* energy potentials, of the various hydro and thermal stations comprising the grid are given in Table I.

TABLE I

NAME OF SCHEME	INSTALLED CAPACITY	DAILY ENERGY POTENTIAL (in eq. MW at 100% L.F.)
Hydro		
1. Tata group (Bhira, Bhivpuri and Khopoli)	261	170*
2. Koyna	540	280†
	801	450
Thermal		
3. Trombay	187·5	187·5‡
4. Chola	118·0	38·0§
5. Tarapore (nuclear)	150	150·0¶
	455·5	375·5
Total system	1256·5	825·5

*Firm energy potential equivalent to 145 MW continuous, increased by 16 per cent, assuming conservation of hydro energy by shutdown during week ends and holidays.

†Based on diversion of 67·5 million cu. ft. which yields 240 MW average and week end conservation of hydro energy as above.

‡Maintenance and emergency standby at Chola.

§Thermal standby of 80 MW.

¶Maharashtra's half share.

With a system daily load factor of 75 per cent the peak demand that can be met would be

$$\frac{825\cdot5}{0\cdot75} = 1100 \text{ MW}$$

From Fig. 2 it would be seen that the hydro stations, with an energy potential of 450 MW (54·5 per cent of the daily requirement), can meet a system peak of 726 MW (66 per cent of the total). The required plant capacity would be available, leaving one of the largest hydro units at Koyna as standby. Thermal plants would then work at 375 MW, i.e. at their maximum firm capacity and energy values. With isolated operation, the peak demand that could have been met on a firm basis is only

$$\frac{(240+145)}{0\cdot75} + 375 = 890 \text{ MW}$$

Co-ordinated operation thus improves system firm capacity by about 220 MW. Hydro energy and plant would be utilized to the best possible advantage in this manner.

From the above it can be concluded that the existing and planned plant capacities in the Bombay-Poona region, hydro and thermal are well matched for co-ordinated operation to meet a maximum demand of about 1100 MW. However, when the Bombay-Poona grid is interconnected with the predominantly thermal Eastern Bushaval-Paras grid, there would be an imbalance which should be restored by planning hydro peaking capacity expansions, wherever possible and appropriate.

Conclusion

It would be seen from the example of the Bombay-Poona system in Maharashtra, that full utilization of hydro and thermal resources would generally be possible if the ratio of hydro and thermal installations is maintained at about 2: 1. This is, of course, on the presumption that the daily load factors would continue to be as high as 75 per cent. If, with freer availability of power and restricted development, the daily load factors reduce, the proportion of hydro plant would have to be higher.

While the above would be generally valid, the problem should be studied in greater detail in the context of the regional grids which are now emerging. In the southern grid region comprising Kerala, Mysore, Madras and Andhra, there are large untapped hydro resources which can economically supply both base and peak demands, and till they are harnessed, hydro-thermal coordination would not appear to be of great immediate importance. In the eastern region of the country comprising Bihar, West Bengal and Orissa where demands for power have hitherto been met largely by thermal stations, their aggregate capacity would be about 1500 MW by the end of the third plan. A far-sighted programme of hydro peaking installations would enable these thermal installations to be utilized to full advantage and fortunately the region has major hydro resources, e.g. Bhimkund, Koel-Karo, etc., which can be considered for the purpose.

Quite apart from the short-term prospects, it is obvious that, on a long-term view, the importance of hydro plants all over the country would shift steadily to their value for peaking purposes. Within the next two or three decades, base load generation would have to come mainly from thermal installation either coal fired or nuclear. It is, therefore, of the greatest importance that hydro schemes currently under consideration should be designed, with large enough water conductor and plant capacities, to enable them to discharge their inevitable further peaking functions.

POWER ENGINEER—SPECIAL NUMBER

We have pleasure in announcing that a SPECIAL NUMBER of POWER ENGINEER will be brought out in April 1961, which will incorporate in it the usual April issue.

The SPECIAL NUMBER will commemorate the successful completion of the ten years by POWER ENGINEER.

The SPECIAL NUMBER will be devoted chiefly to the various aspects of power development in the Second and Third Five Year Plans.

The SPECIAL NUMBER will be issued in lieu of the subscription copy to regular subscribers. For casual orders, the price will be Rs. 4·00 per copy.

Orders for the SPECIAL NUMBER may please be booked in advance. Additional advertising space will also be provided for double colour printing. Clients are requested to apply for additional pages required.

Chambal Power Grid

by **K. S. SIVAPRAKASAM**

WITH the commissioning of the Gandhisagar power station in November 1960, the first stage of power development of the Chambal Valley Development Scheme has been completed. Surveys of transmission lines and construction of the first grid substation was inaugurated in February 1957. The first bucket of concrete for the foundation of power plants in the Gandhisagar power station was laid in October 1957. The erection of the first transmission line tower was started in October 1958. By October 1960, three units of 23,000 kW had been installed at the power station and 647 km. (402 miles) of 132 and 66 kV lines laid out for service. Seven grid substations with an aggregate of 132 MVA transformer capacity and the high and low voltage control gear have been erected in Madhya Pradesh at a total cost of Rs. 9·58 crores. This is perhaps an achievement for any project to be proud of.

Gandhisagar Station

The power station is a 95 m. by 18 m. (311 ft. by 59 ft.) building at the toe of the Gandhisagar Dam on the right flank. It houses four Francis type hydraulic turbines of 34,000 b.h.p. each, complete with its associated water conductor system in the form of the 4·8 m. (15 ft. 6 in.) diameter steel penstock pipes buried in the dam, the scroll casing, the draft tube and other ancillaries. The steel penstock pipes take off from the upstream face of the dam in the form of rectangular bellmouth openings, 3·74 m. (12 ft. 2·4 in.) wide and 4·8 m. (15 ft. 6 in.) high, gradually transitioned into a circular shape by a series of elliptical configurations in concrete, tapering finally to a diameter of 3·76 m. (12 ft. 4 in.) at the scroll case end. Each penstock runs for 40 m. (130 ft. 8 in.) and its thickness varies from 16 mm. ($\frac{5}{8}$ in.) at the high pressure sections at the bottom end to 14 mm. ($\frac{9}{16}$ in.) at the low pressure sections at the upstream end. After passing through the turbine scroll casing, the water discharges into the tail race channel through the turbine and the elbow type draft tube, extending to such a length on the downstream side that the velocity of the water is reduced to a safe 4·6 m. (15·5 ft.) per second. Each draft tube opening is divided into two sections — 3·1 m. (10 ft. 8 in.) wide and 3·66 m. (12 ft. $\frac{3}{8}$ in.) high capable of being covered by a draft tube gate 3·1 m. (10 ft. 8$\frac{3}{8}$ in.) wide and 3·67 m. (12 ft. $\frac{5}{8}$ in.) high weighing about 3·5 metric tonne (3·5 tons).

The entry into the penstock pipes is controlled by the 16·2 metric tonne (16 tons) 3·7 m. (12 ft. 2$\frac{1}{4}$ in.) wide and 5·6 m. (18 ft. 6 in.) high penstock gates operated by 45·7 metric tonne (45 tons) hydraulic hoists in the penstock gate operating chamber. A stoplog or emergency gate, 5 m. (16 ft. 2 in.) wide and 8 m. (26 ft. 8 in.) high of about 20·2 metric tonne (20 tons) is also provided in order to facilitate emergency repairs and maintenance of the penstock gates. The gates are hoisted by a travelling gantry crane of 76 metric tonne (75 tons) with an auxiliary hoisting capacity of 35·5 metric tonne (35 tons). The exit from the draft tube is similarly controlled by the two draft tube gates which are operated by a 10·1 metric tonne (10 tons) gantry crane installed downstream of the power station.

Each turbine is coupled to a vertical shaft umbrella type generator of 23,000 kVA capacity. The turbines and generators of the first three units are of German manufacture, while the fourth is entirely of Japanese make. The Siemens generators embody certain special features such as the electrical shaft system of excitation, neutral isolation and the magnetic amplifier type of voltage regulation. In contrast to these, the Japanese unit is provided with the conventional type.

SHRI K. S. SIVAPRAKASAM is Superintending Engineer, Chambal Hydel Scheme, Madhya Pradesh. Reproduced from *Bhagirath's* Monograph " All About Chambal Valley Development ".

Transmission

The generators and the step-up transformers in the outdoor switchyard are designed to step up the generation voltage of 11 kV to 132 kV before transmission. The switchyard is laid out on the downstream side of the power house, with a duplicate busbar arrangement and 10 bays, at present, each 12 m. (39 ft.) wide, to cater for power demands at Ujjain and Kota over independent 132 kV double circuit lines and to Neemuch and Udaipur over a 132 kV single circuit line. The outdoor structures are of galvanized steel construction, supplied from Italy, along with high voltage switchgear, control and protection panels and control desk for the three German units. The high voltage switchgear and instrument transformers for the fourth unit are supplied from Sweden and some equipment from Japan.

Power for areas in the vicinity of Gandhisagar is made available at 11 kV through two station transformers. The auxiliary supply at the power station is made through the secondary windings of the two transformers as well as from a third station

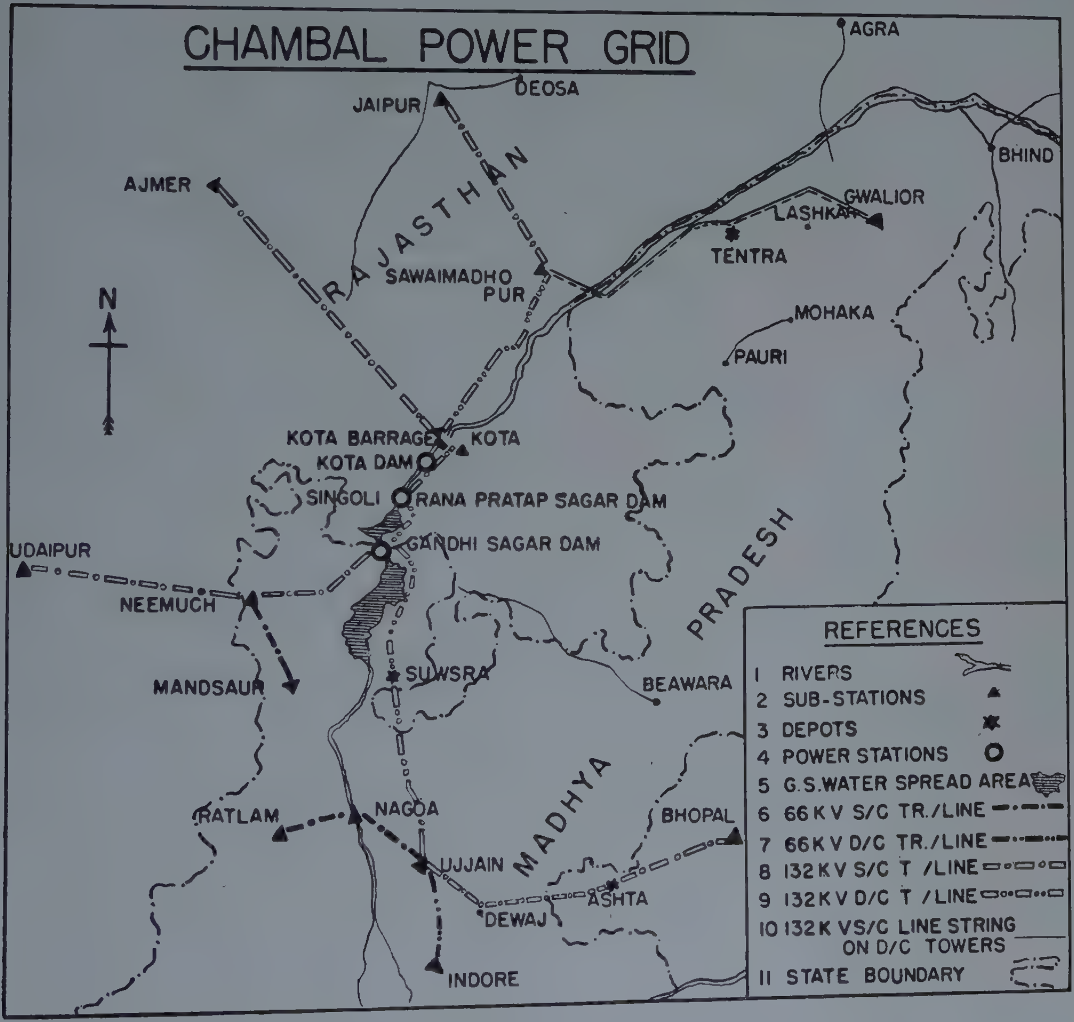

Fig. 1 — Transmission system

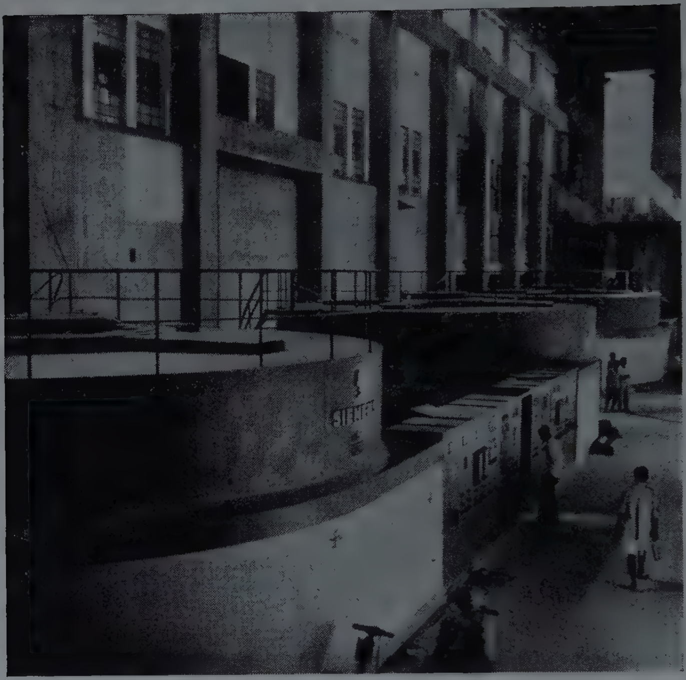

Fig. 2 — A view of the Gandhisagar power station showing the power units

transformer. Provision has also been made for a fourth station transformer for augmenting the 11 kV local supply.

The transmission system under the first stage of Chambal Valley Development spreads far and wide over the States of Madhya Pradesh and Rajasthan. The 132 and 66 kV transmission lines thus carry power to distant major load centres at Ujjain, Indore, Nagada, Ratlam, Bhopal, Neemuch, Mandsaur and Gwalior in Madhya Pradesh and Kota, Ajmer, Jaipur, Udaipur and Sawaimadhopur in Rajasthan. To meet the rising demand for power in these areas, the existing major thermal power stations at Indore, Bhopal, Chandni, Jaipur and the proposed thermal power stations at Jodhpur and Sawaimadhopur are proposed to be interconnected with the Chambal hydel grid.

Chambal Grid

With the installation of the fifth unit at Gandhisagar power station and the

TABLE I—POWER RESOURCES OF CHAMBAL AREA

	Millions of kW		
	1961-62	1965-66	1970-71
Hydro			
Gandhisagar Ranapratapsagar Kota	80·00	175·00	300·00*
Thermal			
Sawaimadhopur	—	60·00	120·00
Jaipur	8·00	8·00	8·00
Jodhpur	—	9·00	9·00
Indore	10·00	10·00	10·00
Bhopal	7·50	7·50	7·50
Chandni	17·00	17·00	17·00
(a)	122·50	286·50	471·50
(b)	105·50		

*Additional peaking capacity of 60,000 kW available at hydro stations due to the Sawaimadhopur thermal station operating at 120,000 kW and 90 per cent load factor.

(a) Assuming that Chandni-Chambal interconnection will be completed by 1961-62.

(b) Assuming that Chandni-Chambal interconnection will not be completed by 1961-62.

completion of the Ranapratapsagar and Kota power stations in the second and third stages, with four 32,000 kW and three 26,000 kW units respectively, the ultimate installed power capacity in this area would be 321,000 kW and the firm power available would be 240,000 kW at 60 per cent load factor, that is 80,000 kW at Gandhisagar, 95,000 kW at Ranapratapsagar and 65,000 kW at Kota power stations.

Growing Demand

Against this, the anticipated power demands of the two states (as per the preliminary report of the Central Water & Power Commission for network analyser studies of the Chambal grid system) are given in Table II.

It will be observed from the above figures that the available power resources in this area are adequate to meet the anticipated demands only up to 1961-62. Thereafter shortage of power begins to be felt. A break-up of the deficit/surplus in the two states indicates that during 1961-62 Rajasthan will have a surplus of 24,500 kW while Madhya Pradesh will face a deficit of from 18,900 to 15,700 kW, depending on whether the Chandni interconnection is effected or not by that time. In 1965-66 Rajasthan also will suffer a deficit of 12,800 kW while Madhya Pradesh's deficit swells up to 42,400 kW; and in 1970-71 the deficit in both the states reaches 23,000 and 79,500 kW respectively.

TABLE II — POWER DEMAND IN CHAMBAL AREA

		MILLIONS OF kW		
		1961-62	1965-66	1970-71
Madhya Pradesh	(a)	93·40	164·40	264·00
	(b)	73·20		
Rajasthan		23·50	177·30	310·00
Total	(a)	116·90	341·70	574·00
	(b)	96·70		

Deficit/Surplus
(a) Plus 5·60 minus 55·20 minus 102·50.
(b) Plus 8·80.

The steady growth of power demand in the Madhya Pradesh area requires that in the period between 1961-62 and 1965-66 Rajasthan and Madhya Pradesh Electricity Boards agree to utilize the total available power to the maximum benefit of the region covered by the Chambal grid. For meeting the power shortages in both the states in later years, immediate action has to be taken for the installation of the fifth unit at the Gandhisagar power station as well as to expedite the construction of the Ranapratapsagar power station for commissioning all the four units by 1965-66.

FOR CONTRIBUTORS TO "POWER ENGINEER"

We are glad to announce that with effect from January 1961, *remuneration will be paid to Contributors, for articles accepted for publication at the rate of Rs.* 25 *or Rs.* 50 *as may be fixed in each case by the Editorial Board.*

Engineers engaged in the field of electric power are requested to send technical papers for publication in POWER ENGINEER.

Electrical Protection of Large Hydro-electric Generators

by **O. D. THAPAR**

HYDRO-ELECTRIC generators running in parallel and connected to long transmission lines require proper protection so that the electrical faults which are fortunately rare but must be detected immediately they occur. It is of prime importance that the protective devices should disconnect the machines automatically if the fault is internal, or if the external conditions are so abnormal that the continued operation would result in damage. With the advent of higher transmission voltages transmitting large blocks of power at long distances, stability problems have increased and operating times of a few cycles have been devised. Before discussing protective schemes and devices, a review of hazards is desirable, because these should be understood when considering the advisability or otherwise of applying specific protective features.

Majority of large hydro-electric generators are cooled by a closed system of air cooling and as such only these will be considered. The discussion is limited to generator protection, but the scope is extended to cover overall protection of generator transformer units.

Possible Faults

Stator Faults — Breakdown of winding insulation may result in any of the following types of faults:

(a) Earth faults
(b) Phase faults
(c) Inter-turn faults

Other faults originating from defective joints or inadequate or defective bracing of end turns or terminals will, if undectected, reach a stage where there is a breakdown of insulation.

A fault to earth is liable to cause, by arcing to the core, not only damage to the conductor but also burning and welding of the laminations. To limit this damage it is almost universal practice to connect an impedance or an earthing resistance between the generator winding neutral and the earth. Practice varies on the method adopted for earthing and the impedance used.

Phase-to-phase or three-phase short circuits are not limited by the earthing impedance.

Rotor Faults — The field system is not normally connected to earth, so an earth fault does not give rise to any fault current and is thus not in itself a danger. If a second earth fault develops, then, however, a portion of the field winding may be short-circuited, resulting in an unbalanced magnetic pull on the rotor. This force may cause excessive pressure on the bearings, with consequent failure of bearing surface or even displacement of the rotor sufficient to bend the shaft. In addition to this mechanical trouble, there is a possibility of overheating of field windings due to the automatic voltage regulator action which may try to maintain the rotor flux in spite of the loss of turns that have been short-circuited by the double earth fault.

Loss of Excitation — Failure of D.C. excitation causes the machine to run as an induction generator, the stator drawing magnetizing currents from the A.C. system. Under such conditions there is a risk of overloading the stator by operating at low power factor, and of overheating the rotor owing to induced currents in the rotor body and damper windings.

Unbalanced Loading — Unbalanced loading is not much of a danger in slow moving hydro-electric generators and is not usually provided for. An unbalanced load can be resolved into positive, negative and zero sequence components. The positive sequence component is similar to the normal balanced load. The negative sequence component is similar except that the resultant reaction field rotates counter to the D.C. field system and produces a flux which cuts

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the rotor at twice the rotational velocity. The double frequency eddy currents thus induced in the rotor are liable to cause heating of the rotor. Water wheel generators have a low rotational velocity and thus the heating in the rotor caused by small eddy currents is of no practical significance.

Overvoltage — Water wheel generators have a high overspeed factor and the provision of overvoltage protection is most desirable so that insulation is not damaged. This protection also serves to avoid damage if the voltage regulator system fails to operate correctly. The potential danger of such failures cannot be ignored with the high speed and great range of modern regulators, designed to meet long distance transmission stability requirements.

Generator Differential Protection

The most common and the most effective method of protecting A.C. generators is by the application of generator differential protection. It acts by comparing the current magnitude at the two ends of a phase winding in its most common form.

Fig. 1 shows the percentage or ratio differential protection around one phase and is most suitable for generator protection specially in cases where the performance of current transformers falls short of requirements due to practical limitations in design or excessive lead burdens and thus results in imperfect matchining of the current transformers. The through fault secondary current circulates through the restraining windings which exerts a restraining force or bias on the movement caused by the operating winding which is energized by the difference in the two current transformer windings. Normally no current flows in the operating coil under through fault conditions, but owing to imperfect matching of the current transformers some spill current may be present. This spill current present due to ratio errors in the operating coil will not cause operation unless the operating restraining (bias) current ratio for which the relay is set is exceeded. The magnitude of the current to cause operation is not constant but automatically increases as the circulating current increases. This gives the relay the advantage of high sensitivity at light loads and decreased sensitivity for external short circuits.

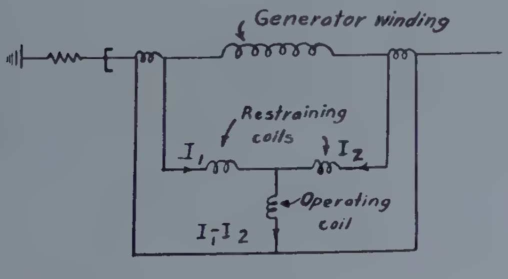


FIG. 1

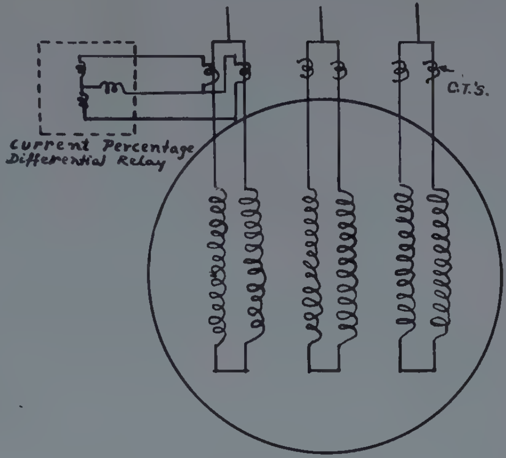


FIG. 2 — CONNECTIONS FOR BALANCED WINDING CURRENT DIFFERENTIAL PROTECTION (RELAY OF THE OTHER TWO PHASES WOULD BE CONNECTED SIMILARLY)

Double Winding and Multiple Winding Generators — The differential winding scheme of Fig. 1 does not detect inter-turn short circuits within the winding because the entering and leaving currents of a phase remain equal. In more important generators having double or multiple winding it is possible to provide this protection. The current in the parallel branches become unequal when turns are short-circuited in one branch (see Fig. 2).

Effect of the Method of Grounding — The method of grounding the generator neutral affects the protection afforded by the differential relays. For example, if sufficient grounding impedance is used so that a ground fault at the generator terminal draws full load current, then for a fault at the mid-point of the winding, the fault current will be approximately one-half of the full load current as only half the phase voltage is available

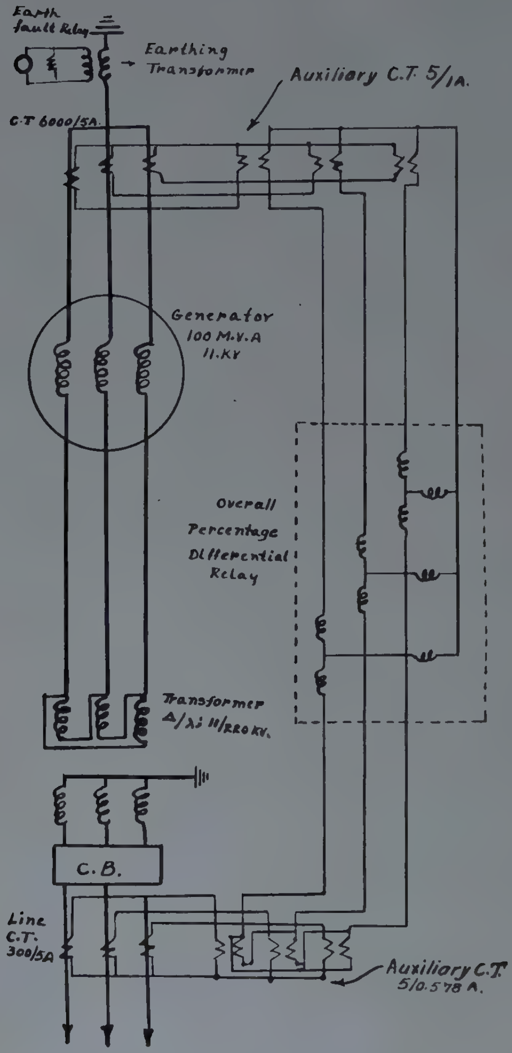

Earth fault Relay
Earthing Transformer
Auxiliary C.T. 5/1A.
C.T 6000/5A.
Generator 100 M.V.A 11.KV
Overall Percentage Differential Relay
Transformer Δ/λ; 11/220 KV.
C.B.
Line C.T. 300/5A
Auxiliary C.T. 5/0.578 A.

FIG. 3 — OVERALL PROTECTION FOR GENERATOR TRANSFORMER UNITS; AUXILIARY 1 AMP. C.T. PROVIDED FOR REDUCING VOLTAGE DROP IN EXTRA LONG LEADS; AUXILIARY C.T. RATIO ON H.V. SIDE IS 5/0·578 ($5/1/\sqrt{3}$) AND SECONDARY WINDING IS DELTA-CONNECTED TO COMPENSATE FOR PHASE SHIFT IN POWER TRANSFORMER

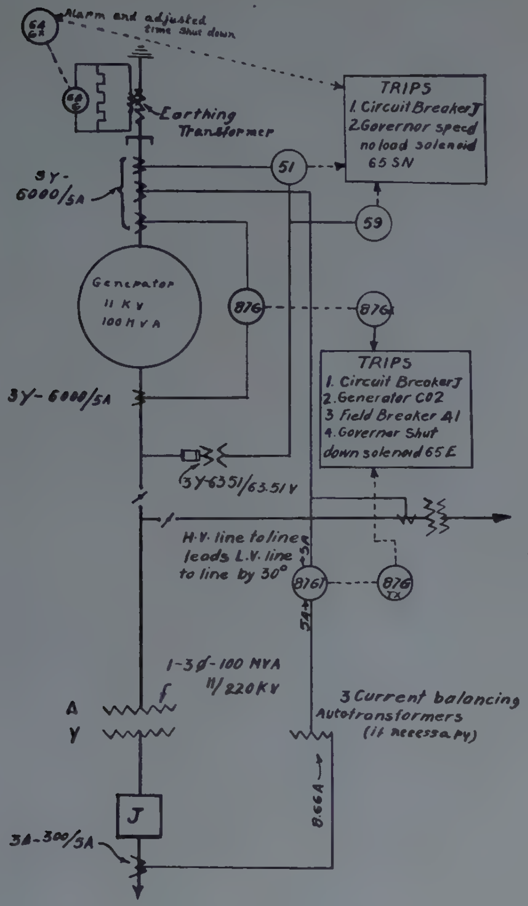
to cause a flow of current. This way a point can be found at which a fault must be placed so as to pass minimum current to operate the relay. The winding above this point is the percentage winding protected against the earth faults. Practically the whole of the winding is protected against phase faults since there is no limiting impedance included in the fault circuit. With a 10 per cent setting about 90 per cent of the winding is protected against earth faults for the case referred to above. The unprotected remainder of the winding is at a relatively low potential above earth and is therefore less likely to become faulty than the protected part. With lower impedance grounding the differential relay protects closer to the neutral. With high impedance grounding, the limit of protection for ground faults is farther from neutral end and for ungrounded machines, the differential protection is inoperative against earth faults.

Generator Transformer Units — Where generator and generator transformer are coupled together as one unit, the main differential protection may be extended to cover both. Fig. 3 shows a typical arrangement. A bias for restraining winding is essential so as to counteract the effect of dissimilar ratios and characteristics of the current transformers during through fault conditions as well as the unbalance caused by power transformer magnetizing inrush current and a tap change of ±10 per cent. These coarser settings cause decrease in the percentage winding protected.

In large hydro-electric generators where due to paucity of space, the distance between switchyard and power plants is occasionally quite substantial, it may be worth while to provide two independent differential protections — one for generators and the other overall for generator and transformer including high tension circuit breaker in its zone (FIG. 4). This arrangement will give proper protection to generator and will also give protection to transformer as well as the tec off for unit auxiliary transformer as a lower setting.

Earth Fault Protection in Unit System — Generator and low phase winding of the power transformer is not directly connected to the system and as such is usually earthed through a much higher impedance than when the generator is connected direct to the system. Practice varies on the method of this earthings.

(i) POTENTIAL TRANSFORMER EARTHING— Protection is provided by a voltage relay (FIG. 5). Normally there is no voltage in the neutral but a ground fault on any part of the circuit comprising generator winding and



[41, field circuit breaker; 51, overcurrent voltage restraint relay; 59, overvoltage relay; 64G, generator earth fault relay; 64GX, auxiliary relay for 64G; 87G, generator differential relay; 87GX, auxiliary relay for 87G; 87GT, overall differential relay; 87GTX, auxiliary relay for 87GT; 65E, governor shutdown solenoid; 65SN, governor speed no load solenoid]

FIG. 4 — TYPICAL GENERATOR PROTECTION SINGLE LINE DIAGRAM FOR 100 MVA GENERATOR

connecting leads to power transformer and its low voltage winding will produce a voltage on the relay which can be used for tripping or alarm purposes. In this case the setting must be coarse so as to avoid false tripping due to harmonic voltage and false indications due to ground faults on high tension system caused by zero sequence capacity coupling between high voltage and low voltage windings of the step-up transformer.

(ii) LIGHT RESISTANCE GROUNDING — This scheme consists of earthing the generator, connecting leads and low phase winding of the power transformer through a small distribution transformer loaded with a resistor on its secondary side. This method of earthing is more suitable to the unit system of design and overcomes some of the defects as mentioned for above potential transformer earthing. The protection provided consists in connecting a voltage relay in parallel or a current relay in series with resistor (see Fig. 6) so as to sound an alarm or to trip. A combination of sensitive alarm and coarser trip or of alarm and time delay trip are also used. The latter gives time to transfer the load to another machine at the hazard of operating with a fault on one phase. These devices supplement generator differential protection so as to provide indication or tripping for ground faults.

Rotor Faults

A scheme for protection against earth faults is shown in Fig. 7. The earth fault protective gear consists of centre-tapped resistor connected across the field winding and a sensitive relay connected between the centre tap and earth. These are equipotential points so long as there is no earth fault on the winding. The occurrence of an earth fault, however, upsets the balance and the

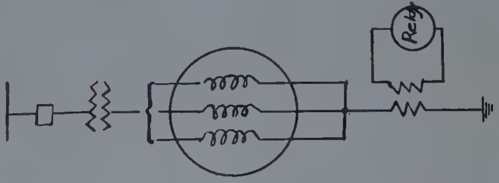


FIG. 5 — POTENTIAL TRANSFORMER EARTHING OF ISOLATED NEUTRAL GENERATOR

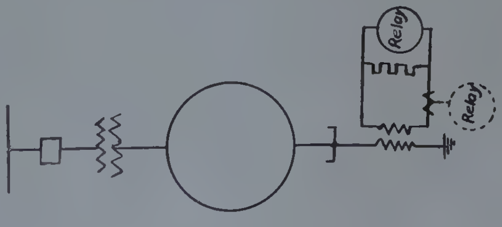


FIG. 6 — GROUNDING SCHEME FOR UNIT SYSTEM

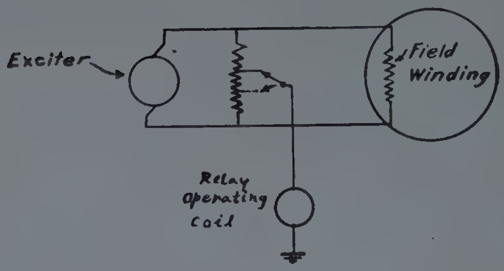


FIG. 7 — ROTOR EARTH FAULT PROTECTION

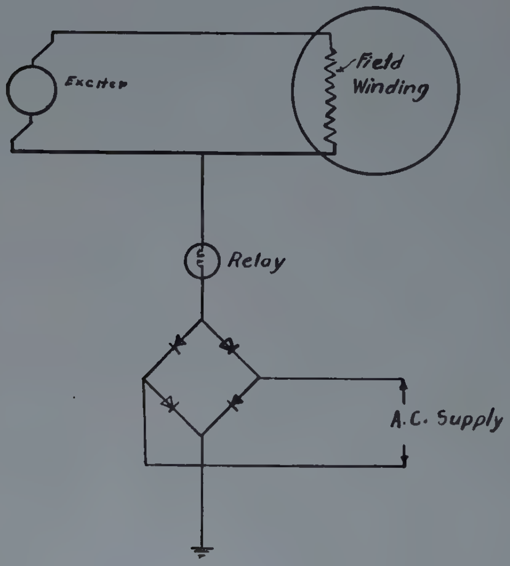


FIG. 8(a) — ROTOR EARTH FAULT PROTECTION

relay is operated and usually gives the alarm. The relay will response to earth fault occurring over most of the rotor circuit and about 95 per cent of field winding can be protected. If the tap on the resistor is varied then complete protection can be afforded.

Alternative A.C. schemes are shown in Figs. 8(a) and 8(b). These schemes provide complete coverage to the rotor windings. In Fig. 8(a) the field circuit is biased relative to earth by means of a small transformer rectifier unit connected between the positive pole of the field system and the earth, a highly sensitive relay being included in this connection. The positive pole of the field system is biased about say 40 volts negative to earth and the remaining portion of the field circuit is proportionately more negative. A fault occurring at any point in the field system will apply a voltage to the relay which is sufficient to cause operation by the potential relay.

In Fig. 8(b) one point of the field circuit is earthed through a static condenser. The protective condenser is in series with the capacity of the complete exciter circuit. In case of an earth fault in the field circuit, the secondary circuit of the auxiliary transformer is closed through the relay, condenser and part of the field circuit and earth fault causing the relay to operate.

The relay is usually arranged to give alarm only.

Field Failure

A current relay in the rotor circuit is usually all that is required to supervise the field

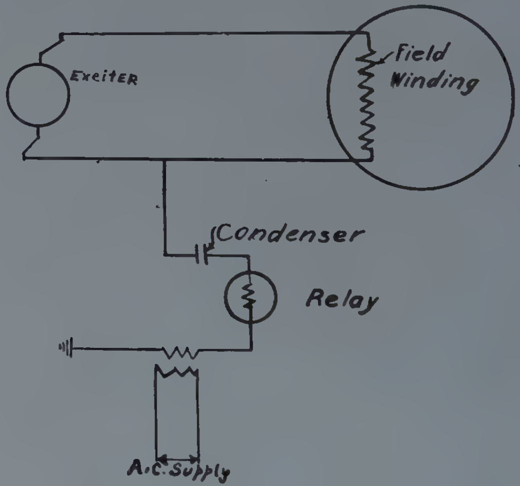


FIG. 8(b) — ROTOR EARTH FAULT PROTECTION

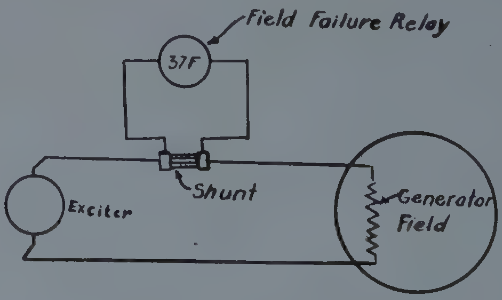


FIG. 9 — FIELD FAILURE RELAY

system. Modern voltage regulators are liable to vary the field current over a wide range and under certain circumstances may swing down to about 20-25 per cent of no load excitation value. The relay should not respond to these transient effects and a low setting with time delay feature is thus required. Fig. 9 shows the connections.

Back-up Overcurrent Protection

Back-up overcurrent protection may be provided to generator either (i) as standby protection against sustained faults in the network or (ii) as a safeguard against failure of the generator unit protection.

In connection with the first case, the question of setting must be very carefully considered and the rapid decrement of fault current fed by the generator must be taken into account. It is important that the generator is not tripped as a result of system faults even though the generator is operating under its maximum excitation condition and the relay setting must be chosen to discriminate with the outgoing circuit protection. The main aim is to provide a back-up protection and the overcurrent relays are set, not so much with the intention of tripping under through faults but rather to guard against fault currents fed back from the system upon the occurrence of an in-zone fault. So it is most usually provided with a voltage restraint and inverse time delay feature so that tripping occurs only in case there is a fall in the generator voltage.

In the second use, the overcurrent relay serves as a very useful standby system of protection for such periods as, for example, when the differential protection is being tested at which time the overcurrent settings can be varied at discretion to suit the temporary condition.

With the advent of modern static quick response type automatic voltage regulators controlling large reserves of excitation power, the generator circuit decrement in fault condition is delayed so that overcurrent time setting can be so chosen as to give back-up cover against through fault conditions as well. In such cases, however, possible variation in current time values must be kept in mind when regulator is out of circuit for maintenance.

In general the question whether or not back-up overcurrent protection is to be fitted to a generator and what time and current settings should be used must be considered separately for each installation in the light of discussion as above.

Overvoltage Protection

The setting of this relay should be as high as possible and a figure of 150 per cent may be adopted. It is usually quite sufficient to provide a single phase relay.

Conclusion

The above is a general discussion of the principal electrical schemes applied to water wheel generators — these do not cover every contingency in every case. Almost every station has got its own peculiar circumstances and while differential protection is regarded as essential, the others are mainly optional and need selection with discretion.

Electrical Clearances in Outdoor High Voltage Substations

by **H. R. KULKARNI**

IN the past, the practice followed in the selection of the electrical clearances in substations was largely based on experience coupled with a measure of empiricism. In recent years a great deal of work has been devoted to this subject and on the basis of the experimental data and large volume of statistics collected, a rational approach to the subject has been evolved. This has revealed that there is ample scope for reducing clearance distance adopted in the past and effect substantial economies in the cost of structures and space requirements.

Clearances adopted in this country are not only very liberal but also differ from one system to another and often within the same system. Some of the commonly adopted clearances are indicated in Table I, which shows the multiplicity and disparity between them. At this time, when construction of power supply facilities is expanding at a phenomenal rate and planning is being done on an even larger scale, it may be of great benefit to review the modern approach to this problem in line with the present trends in world practice. It is hoped that this review will permit standardization on a national plane which will be highly conducive to economy and speed of execution.

Criteria for Determining Clearances

The criteria for determining the insulation level in a substation, as in the case of any other equipment, is the voltages to which the system is subjected or is likely to be exposed during service. These voltages are:

(a) Operating voltage
(b) Steady state voltages under abnormal conditions
(c) Switching-over voltages
(d) Lightning surges

The same factors should naturally form the criteria for selection of electrical clearance in air. The minimum clearance which can withstand all these voltages would be the appropriate clearance to adopt. It is seen in practice that the severity of these influences increase in the order stated and that the requirements for withstanding the lightning surge voltages are the most exacting. If this condition is fulfilled therefore, the other requirements are usually automatically taken care of.

The insulation of the various components of the substation such as transformers, circuit breakers, isolators, bus insulators, etc., is already determined on this basis and the actual choice of any particular insulation level is confined to a set of standard values which have been widely adopted as industrial standard. For a properly designed substation the insulation levels of the various components have to be co-ordinated with one another as well as with respect to the protective level afforded by protective devices such as lightning arresters. It will be readily seen that the selection of electrical clearances should also be appropriately co-ordinated with the insulation level chosen for the other substation components. Since the other equipment insulation levels are standardized, it follows, as a corollary, that electrical clearances corresponding to these insulation levels should also be standardized.

The margins of safety provided for the various substation components should be carefully matched, since strengthening one link in a chain does not add to the strength of the chain, as its strength is limited by the weakest link. No practical purpose is thus served by unduly increasing the margin of safety only in some components. The electrical clearances to be provided in a substation should, therefore, have margins of safety which are properly co-ordinated with the margins allowed for the other equipment,

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in order to obtain the best overall design with optimum economy.

For arriving at the co-ordinated clearances, it is essential as a first step to have the dielectric characteristics of air, such as power frequency flashover, switching surge strength, impulse flashover characteristics, etc. A number of investigators has determined these characteristics using various arrangements of the electrodes, the most common arrangement being the rod gap. As a result of these investigations, rod gap characteristics have been determined with a great degree of accuracy which have received general acceptance. These characteristics are shown in Fig. 1.

The behaviour of air under switching surges has been investigated in recent years and it is found that its dielectric strength for switching surges, normally encountered in the power systems, averages about 90 per cent of the dielectric strength for standard impulse voltages. Since the switching surges expected in practice do not generally exceed 3·5 times the operating voltage to neutral and the standard impulse levels are about 5-10 times the operating voltage to neutral, adequate safety margin is automatically provided against switching surges, if impulse conditions are taken care of.

Air gap flashover characteristics, as determined under laboratory conditions, cannot be directly used for determining the clearance in air since the shape and size of the electrodes and the ground structure obtaining in a substation differ greatly from the standard rod gap, resulting in very different dielectric field which determines the flashover characteristics. The next step is to determine as to how the characteristics obtained under standard laboratory conditions can be correlated with the characteristics that may be actually exhibited under field conditions. The atmospheric conditions in practice would also be different from the laboratory conditions and would further

TABLE I — ELECTRICAL CLEARANCES ADOPTED IN OUTDOOR SUBSTATIONS

VOLTAGE (kV)	CLEARANCE BETWEEN PHASE AND EARTHED PARTS			CLEARANCE PHASE-TO-PHASE			ACTUAL SPACING BETWEEN BUSBARS ℄ to ℄			SAFETY CLEARANCE		
	ft.	in.	approx. metres	ft.	in.	approx. metres	ft.	in.	approx. metres	ft.	in.	approx. metres
220	7	6	2·29	16	0	4·88	16	0	4·88	25	0	7·62
				14	9	4·50	16	5	5·00	16	0	4·88
				14	0	4·27				15	0	4·57
132	3	10	1·17	9	0	2·74	16	9	5·11	14	3	4·34
				8	2	2·49	15	6	4·72	17	4	5·28
				8	0	2·44	16	10	5·13	15	0	4·57
				9	2	2·79	10	0	3·05			
				8	9	2·67	15	0	4·57	16	0	4·88
				5	6	1·68	9	0	2·74	17	0	5·18
110	4	6	1·37	8	6	2·59	10	9	3·28	12	0	3·66
	3	4	1·02	5	6	1·68				15	0	4·57
66	3	6	1·07	6	0	1·83	14	3	4·34	12	9	3·89
	2	6	0·76	4	11	1·50	8	6	2·59	14	5	4·39
				4	6	1·37	11	6	3·51	12	0	3·66
				5	0	1·52	5	6	1·68	15	0	4·57
							7	0	2·13			
				4	0	1·22	9	9	2·97			
33	2	6	0·76	4	6	1·37	9	0	2·74	12	0	3·66
	1	2	0·36	2	6	0·76	2	6	0·76	13	2	4·01
	2	0	0·61	4	0	1·22	6	6	1·98	11	6	3·51
				5	0	1·52	5	6	1·68	11	0	3·35
				3	0	0·91	6	0	1·83			
				2	0	0·61	4	0	1·22			
22	2	0	0·61	3	0	0·91	8	8	2·64	12	0	3·66
	1	6	0·46	2	0	0·61						
11	1	6	0·46	2	6	0·76	8	6	2·59	12	0	3·66
	1	0	0·30	1	6	0·46						

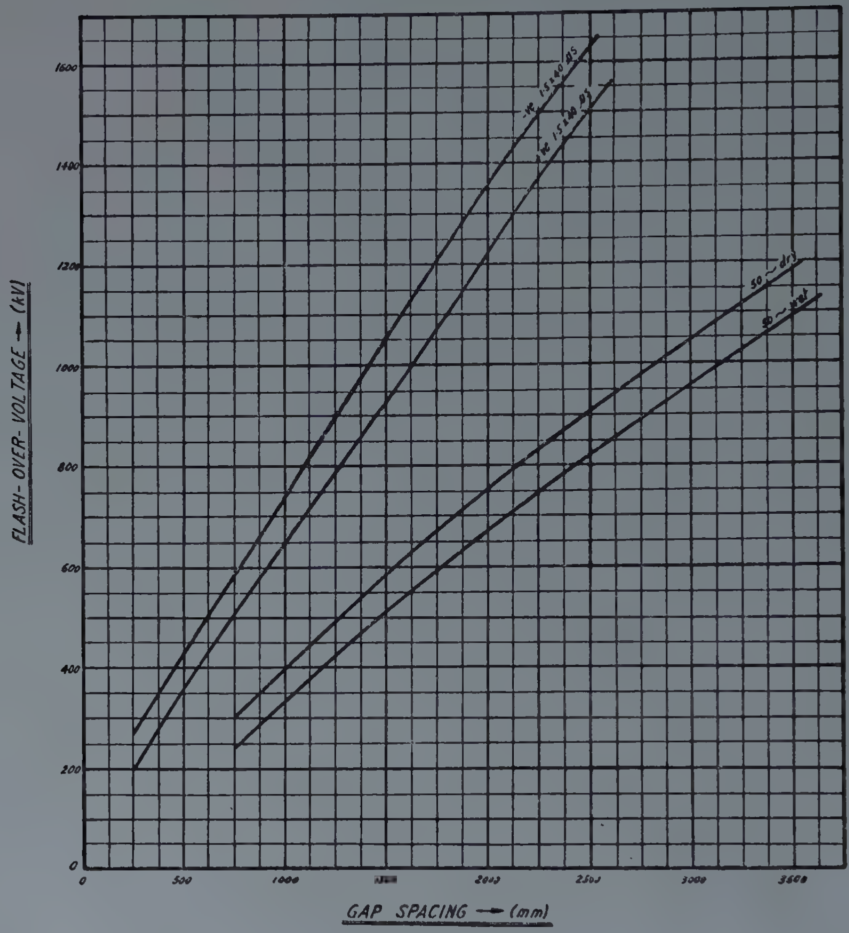

FIG. 1

be subjected to diurnal and seasonal variations. An allowance for these factors has to be made in using the rod gap characteristics for determining the electrical clearances.

The earliest concerted effort in this direction for rationalizing electrical clearances was made by the American Institute of Electrical Engineers, who constituted a committee for this purpose in 1954. The basic approach in arriving at the electrical clearances was to determine firstly the standard rod gap distance which would have an insulation strength equal to the selected standard insulation level and then to apply various factors to account for non-standard conditions obtaining in practice and for providing additional safety margins.

Phase-to-ground Clearances

Flashover from phase to ground in an actual installation, such as from buses to beams, switch parts to structures, insulator live parts to ground wires, etc., do not follow rod gap flashover characteristics very closely because of the different electric field patterns. However, it has been established from extensive laboratory tests that flashover values under such conditions are not generally more than 12 per cent below the rod gap flashover voltages. A factor of 12 per cent has therefore been adopted to provide for the possible lowering of the insulation strength of air due to variations in the configurations occurring in practical outdoor substations.

Since the intention is to prevent flashover, a factor has to be applied over the actual flashover value to obtain a dielectric strength which will withstand the corresponding voltage. This factor, which converts the distance corresponding to the certain flashover voltages into the nearest distance which can safely withstand the same voltage, is taken at 110 per cent of the flashover distance. There can be two ways of applying these factors. They may be applied to the voltages and then the clearance determined corresponding to the flashover voltage thus obtained or the clearance corresponding to the actual flashover voltage can be determined and the factors applied to this clearance. Both the procedures will give approximately the same results since the air gap characteristic is practically a straight line.

The clearances worked out in accordance with the procedure outlined above are shown in Table II, col. 6. The operating voltages adopted in this table are taken from the Indian Standard 585: 1954 and the corresponding impulse levels are adopted from International Electrotechnical Commission specifications, as these are recommended for acceptance by Indian Standards Institution.

The International Electrotechnical Commission (I.E.C.) is also working on standardization of clearances in air. The recommendations contained in their draft are based on a somewhat different approach. They have based the clearances on the flashover distances of the rod-and-the-ground-plane gap rather than on the rod gap. This gap approaches the worst conditions which can be obtained in practice and give lower flashover values than the standard rod gap. The factors applied in the preceding discussion for allowing for the possible departures from the rod gap characteristics are, therefore, not necessary in this case. For the sake of comparison, the clearances recommended in the draft I.E.C. are shown in col. 8 of Table II. It will be noticed that these clearances are somewhat higher than those worked out in col. 6.

The clearances recommended in the British Standard 159: 1957 and those contained in the Swedish Standard SEN-32 are plotted in Fig. 2. It will be seen that the clearances recommended in these are lower than those in the I.E.C. for voltages above 110 kV and are much nearer the clearances worked out in col. 6. It is considered by many that the clearances obtained from the grounded plane and rod gap are generally very conservative as a configuration represented by it is not likely to be obtained in substation practice.

The clearances recommended in col. 7 are also plotted in Fig. 2 for comparison. These phase-to-ground clearances form the foundation on which other clearances are worked out.

TABLE II — PHASE-TO-GROUND CLEARANCE CO-ORDINATION WITH SYSTEM IMPULSE LEVEL

NOMINAL SYSTEM VOLTAGE (kV) (1)	MAXIMUM SYSTEM VOLTAGE (kV) (2)	IMPULSE WITHSTAND LEVEL (kV) (3)	ROD GAP CORRESPONDING TO F.O.V. IN COL. 3 (mm.) (4)	AIR GAP WITHSTAND DISTANCE 1·1 × COL. 4 (mm.) (5)	MIN. PHASE-TO-GROUND CLEARANCE 1·12 × COL. 5 (mm.) (6)	MIN. PHASE-TO-GROUND CLEARANCE RECOMMENDED (mm.) (7)	MIN. PHASE-TO-GROUND CLEARANCE AS PER DRAFT I.E.C. (mm.) (8)
11	12	75/95	77/100	84·7/121	110/150	150	130
22	24	125	130	143	160	200	220
33	36	170	225	246	276	300	320
66	72·5	320	440	484	542	600	630
110	123	450	670	737	825	850	920
110/132	123/145	550	830	913	1030	1050	1150
132	145	650	1020	1120	1260	1300	1380
220	245	825	1320	1452	1630	1650	1800
220	245	900	1450	1595	1790	1800	1960
220	245	1050	1720	1892	2110	2100	2300

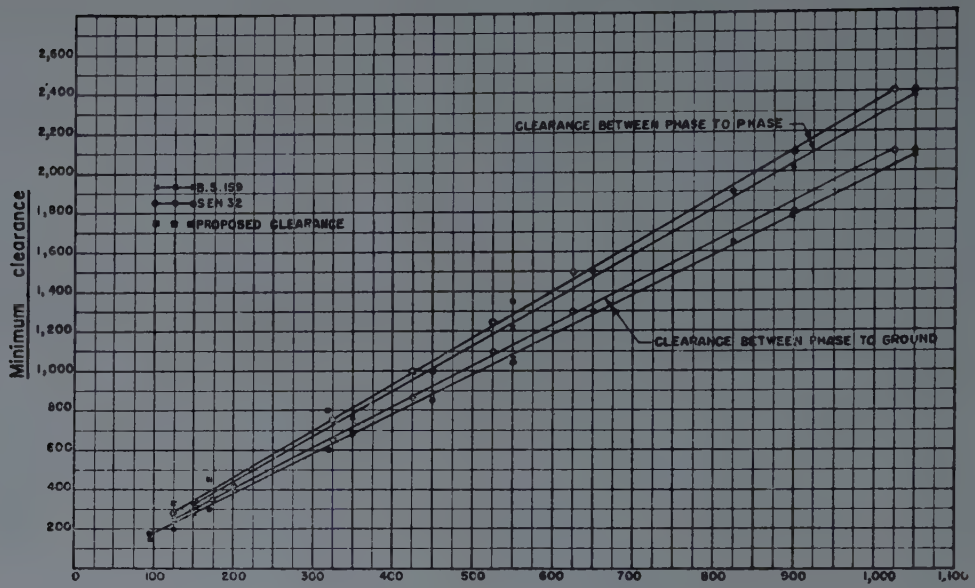

Fig. 2 — Impulse withstand level kV (1×50 μsec.)

Phase-to-phase Clearances

Adoption of a phase-to-phase clearance equal to 1·73 times a phase-to-ground clearance appears to have been the common practice in the past. This is obviously based on the argument that the phase-to-phase voltage is 1·73 times the phase-to-ground voltage and hence a phase-to-phase clearance should bear the same ratio to the phase-to-ground clearance. The argument is obviously fallacious since the phase-to-ground clearance is not determined on the basis of the phase-to-ground operating voltage but is determined on the basis of impulse voltages.

The phase-to-ground clearance is actually determined on the basis of lightning overvoltages as already seen in the preceding paragraphs, and the lightning voltages between phases are not 1·73 times the lightning surge voltage between phase to ground. The logical method of arriving at the spacing of busbars, therefore, is to base them on the following considerations:

(i) The phase-to-phase clearance should be greater than the phase-to-ground clearance in order to ensure that in the event of a flashover, the flashover occurs between phase to ground rather than between phase to phase, as the latter may lead to more severe consequences.

(ii) The phase-to-phase clearance should have flashover voltage higher than the flashover voltage of the bus supporting insulators in order to ensure that the dielectric strength of the bus supporting insulators is fully utilized.

In regard to (i), it is considered adequate to allow a factor of 10 per cent over the phase-to-ground clearance. For proper co-ordination of the phase-to-phase clearance with the insulator flashover, indicated in (ii), the same procedure as adopted for determining the phase-to-ground clearance is followed. This consists of allowing a factor of 10 per cent margin of safety and a factor of 12 per cent to take into account the non-standard electrode configurations obtaining in practice. To illustrate this procedure the phase-to-phase clearance for busbars has been worked out in this manner in Tables III and IV.

The values of bus insulator flashover voltages required for the determination of phase-to-phase clearance, shown in col. 4 and 5 of Table IV, are taken from manufacturers catalogues, corresponding to the

N.E.M.A. standard insulators. The technical reference numbers (T.R. No.) are indicated in col. 3. The co-ordinating rod gap distances in col. 6 and 7 are corresponding to the impulse flashover voltages for positive and negative waves respectively. The higher of these spacings would naturally determine the phase-to-phase busbar clearances. It may be noted here that the positive flashover voltage for cap and pin type insulators is much higher than the negative flashover and thus dictates the phase-to-phase clearance.

In the case of disc insulator strings, this characteristic is not exhibited. The positive and negative flashover values are much closer together and hence the rod gap distance which co-ordinates with F.O.V. characteristic of disc insulator strings are appreciably

TABLE III — PHASE-TO-PHASE CLEARANCE CO-ORDINATION WITH BUS INSULATOR CHARACTERISTICS (STRAIN INSULATORS)

System nom. voltage (kV)	System impulse level (kV)	No. of discs in string	Impulse F.O.V. of string		Co-ordinating rod gap for		Phase-to-phase spacing col. 6 × 1·1 × 1·12 (mm.)	Clearance 1·1 × col. 6 (Table II)	Recommended phase-to-phase clearance (mm.)
			Positive wave (kV)	Negative wave (kV)	Positive wave (mm.)	Negative wave (mm.)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11	75/95	1 10″ × 5¾″	125	130	125	35	155	165	170
22	125	2 6″ × 5½″	200	180	250	100	310	220	330
33	170	2 10″ × 5¾″	250	250	345	220	425	330	450
66	320	4 10″ × 5¾″	440	415	640	475	790	660	800
110	450	5 10″ × 5¾″	525	495	780	593	960	940	1000
110/132	550	7 10″ × 5¾″	695	670	1095	885	1350	1160	1350
132	650	8 10″ × 5¾″	780	760	1220	1040	1500	1430	1500
220	825	10 10″ × 5¾″	945	930	1560	1300	1920	1820	1900
220	900	11 10″ × 5¾″	1025	1015	1680	1440	2065	1980	2100
220	1050	13 10″ × 5¾″	1185	1190	1935	1720	2380	2310	2400

TABLE IV — PHASE-TO-PHASE CLEARANCE CO-ORDINATION WITH BUS INSULATOR CHARACTERISTICS (STACKING INSULATORS)

System nom. voltage (kV)	System impulse level (kV)	T.R. No. × N.E.M.A.	Impulse F.O.V.		Co-ordinzting rod gap for		Phase-to-phase spacing col. 7 × 1·1 × 1·12 (mm.)	Clearance 1·1 × col.6 (Table II)	Recommended phase-to-phase clearance (mm.)
			Positive wave (kV)	Negative wave (kV)	Positive wave (mm.)	Negative wave (mm.)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11	95	1 × 4	125	200	125	125	155	165	170
22	125	1 × 7	170	250	205	220	271	220	280
33	170	1 × 10	225	290	290	282	356	330	360
66	320	2 × 56	410	540	580	672	827	660	830
110	450	3 × 19	610	780	940	1060	1304	940	1310
110/132	550	3 × 19	610	780	940	1060	1304	1160	1310
132	650*	4 × 25	810	1020	1290	1440	1770	1430	1770
220	825†	5 × 126	1010	1240	1655	1800	2215	1820	2220
220	900	5 × 126	1010	1240	1655	1800	2215	1980	2220
220	1050	6 × 128	1210	1450	1990	2160	2655	2310	2660

*Insulator stacks rated at 650 kV not available in N.E.M.A.; 750 kV rated stack used for co-ordination. If 650 kV stack is available, the co-ordinating gap will be about 50 in. and corresponding phase spacing will be 62 in. or 1580 mm.

†Insulator stack rated at 825 kV not available in N.E.M.A. Standard; 900 kV rated stack used for co-ordination. If 825 kV stack is available co-ordinating gap will be about 65 in. and corresponding phase spacing will be 80 in. or 2020 mm.

TABLE V — SAFETY CLEARANCE

System maximum voltage (kV)	System impulse level (kV)	Phase-to-ground clearance (mm.)	Allowance for man's reach (mm.)	Safety clearance (m.)
12	95	150	2400	2·5
24	125	200	2400	2·6
36	170	300	2400	2·7
72·5	320	600	2400	3·0
123	450	850	2400	3·3
123/145	550	1050	2400	3·5
145	650	1300	2400	3·7
245	825	1650	2400	4·1
245	900	1800	2400	4·2
245	1050	2100	2400	4·5

smaller. It is, however, possible to take advantage of lower spacings even in the case of stacking insulators by providing arcing horns on the insulator stacks in a substation. The bus spacings for disc insulator strings are worked out in Table III. The clearances between phases worked out for the strain type of bus insulators are found to agree fairly well with those recommended in the Swedish Standard SEN-32. The clearances adopted by SEN-32, B.S. 159 and those proposed herein are plotted in Fig. 2 for comparison.

Safety Clearance

The various national electricity regulations generally stipulate the minimum safety clearance. This is the clearance between any live object and the nearest grounded or 'dead' object to which a man can have access. This safety clearance should be such as to ensure the safety of operating personnel in the substation premises. It is determined by adding to the relevant phase-to-ground clearance the distance of 'man's reach'. According to the British practice, this reach is taken 8 ft. which is the distance a fairly tall man can reach with his hands outstretched. This distance of reach is taken to be the same in all directions. The American practice takes 8½ ft. as the vertical reach and 3½ ft. as the horizontal reach, on the assumption that the man is always standing on his feet. The British practice of assuming the same reach in all directions has the advantage, that in case the man trips, the safety clearance will be maintained even when he assumes a horizontal position in the process of falling.

In view of this consideration and the fact that in general men are not as tall in our country as in America, it appears preferable to adopt a reach of 2·4 m. for our country which is slightly more than 8 ft. Accordingly the safety clearance is determined by adding 2·4 m. to the phase-to-ground clearance. The values rounded off to the nearest 10 cm. are shown in Table V. It should be mentioned here that if any mobile or other mechanical equipment is intended to be used for maintenance of the substation, which would require the presence of a man to a higher level than the ground level, then the corresponding height of such equipment has to be added further to this overhead clearance.

Other Factors to be Considered

While the clearances given in Tables II and V are intended for use as standard, the choice of actual spacings, to be adopted in any particular case, would further be influenced by other factors such as the space requirements for maintenance of various items of equipment, their removal to maintenance bays, requirements of fixtures needed for dismantling, etc. Further, the main phase-to-phase clearances are applicable under the worst conditions, such as maximum saga and wind conditions which might result in swinging the bus conductors towards each other. The effect of altitude (if over 1000 m.) and the degree of pollution of atmosphere have also to be taken into account. Due allowance has to be made for these factors before finally deciding upon the spacings and clearances.

To evaluate the conductor swing, it may be in order to take the maximum swing under the local wind load conditions and assume that no adjacent conductors may swing towards each other in opposite phase under the worst possible conditions. While this may be adopted for busbars where a flashover may cause a shutdown of the whole station, only 90° out of phase swinging may be an adequate assumption for the other circuits. As a thumb rule the angle of swing can be taken as 45°.

The question of birds flying between the busbars or perching on them is often raised while deciding on the clearances. But it should be borne in mind that it is very improbable for a bird to be playing about in a substation at the same time when a lightning storm hits it. Under normal operating conditions there is enough clearance to withstand safely the reduction caused by birds playing about. It is therefore not justifiable to pile up a further factor of safety on this account.

Clearance between Circuits at Different Voltages

While designing a substation having more than two voltages, the question of taking circuits of different voltages over or across one another is often encountered. The minimum clearance to be provided between them should be the same as the phase-to-phase clearance corresponding to the higher voltage. If, however, it is necessary to allow for maintenance of one circuit while the other is live, then this clearance will have to be increased to a value which will give the corresponding safety clearance between the live point and the grounded structures on which the maintenance personnel are likely to stand.

Conclusion

It would be seen from the foregoing that even though the phase-to-ground clearances worked out here agree very well with those adopted in practice so far in many countries, the phase-to-phase and safety clearances which can be justified on a rational basis are considerably lower than those used in practice. The adoption of the lower clearances would undoubtedly result in substantial savings in the substation structure, without involving any lower degree of safety. Further, it will lead to more compact station designs which could be more efficiently protected from atmospheric overvoltages and travelling surges by the lightning arresters provided in the substation. Some of the large utilities in Canada have already used these reduced phase-to-phase spacings with success. While some American utilities have also adopted these clearances for the higher range of voltages, they are now advocating their use even for lower voltage classes. There should, therefore, be no hesitation to adopt these clearances in this country.

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Some Observations Regarding Thunderstorms and Lightning Surges on Transmission Lines

by **S. SZAFRANSKI**

Physical Aspect of Thunderstorms

EARTH'S *Electric Field* — It is now well known that the earth is enveloped by an electrical vertical field which has as the negative electrode the earth globe and as a positive electrode a concentric sphere formed by a layer of positive ions (Heaviside layer) situated at a height of 100-150 km. above the ground.

The intensity of this electric field near the ground surface is of the order of 100 volts/m., but is influenced by the topographical configuration, local space charges and also undergoes variations in time.

Due to the conductivity of the air the external spherical envelope is continuously being discharged and the electrical field would disappear in the course of time, but for the charge being constantly renewed by the ascending currents of hot air which carry the positive ions. The latter are partly produced in the ground (by collision process of fast moving electrons from radioactive substances, alpha and gamma rays, thermal agitation, etc.) and partly by cosmic rays, ultraviolet rays of sunlight and similar sources of radiation. The consequent electrical current amounts to roughly 1800 amps. over the whole surface of the earth. There is much evidence that the earth's electric field is also created and maintained by the action of thunderstorms and lightning strokes occurring over the surface of the earth.

Cloud Charge — The formation of a cloud charge depends on two distinct processes: firstly, a production of positively and negatively charged particles (water drops, ice or snow), and secondly, by the separation in the space of the particles of opposite polarity (i.e. the polarization of the cloud).

There is still some considerable doubt regarding the charging mechanism at work in a cloud, but the recent laboratory experiments seem to prove that when the water of degree of purity found in the rain drops is freezing very high electric potentials arise between the water phase and the ice phase. The direction of the potential difference depends upon the nature of the impurities dissolved in water. It is also possible that the positive charge observed on the large drops arises from the process of spray electrification of water drops in the turbulent region at the base of the cloud.

Once high electrostatic fields are established in the clouds the charging by ion movement and polarization of falling rain drops takes place.

In the course of time the charges within the cloud become separated and the cloud forms its own field with parts of the cloud being positive and other parts negative — this may look approximately as shown in Fig. 1. Thus the cloud's electric field becomes superimposed on the earth's own field. Since the ground presents a conducting surface, the negative and positive charges within the cloud do not need to be necessarily equal.

Thunderstorm Cell—The thundercloud is created by any set of circumstances which lead to the heating and humidification of the air nearest the earth to such an extent that a strong convective updraft unit called *a cell* is formed. The conditions which produce such convective centres may be arising from the following:

(i) High ground temperatures (as in summer thunder showers)
(ii) Air mass movements (frontal storm systems in monsoon)
(iii) Volcanic eruptions or local heating of unusual origin

No electrification will occur unless the convection carries surface air well above the

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freezing isotherm. Updraft velocities that have been measured range from 2 to 70 miles/hr. or even higher. The thunderstorm cell is not stationary in one position relative to the earth and is accompanied by considerable wind which displaces the cloud. Most of the positive charge of the cell is at the top of the storm cloud and the main negative charge is placed in the section of the cloud where updrafts and downdrafts are most prominent, therefore the majority of the rain falling from thunderclouds is negatively charged.

The diameter of the cell which stores the major portion of the charge active in lightning strokes is generally below some 4 km. The density of charge in a cloud can range between 38 and 120 e.s.u./m.^{3} Thus about 6 km.^{3} of average size of cell would carry approximately 240 coulombs.

Under the thunderstorm clouds the potential of the ground is usually positive and the ground field ranges from 0 to about 50 volts/cm. as against 1 volt/cm. of negative fair weather gradient of vertical field. Consequently, if a pointed earthed conductor rises say 10 m. above the ground, the potential between it and the air surrounding the tip would be as much as 5×10^4 volts — it is clear that any relatively high object under the thundercloud may initiate a discharge of the advancing pilot leader.

Lightning Stroke — The average height of the thunder cell above the ground is often 2 km. The height of the cloud base to the top of the negative charge in the cell is closely correlated with the number of strokes that come from the cell. The number of successives trokes down the same channel from the same cell increases progressively with the height of the cell as indicated in Table I.

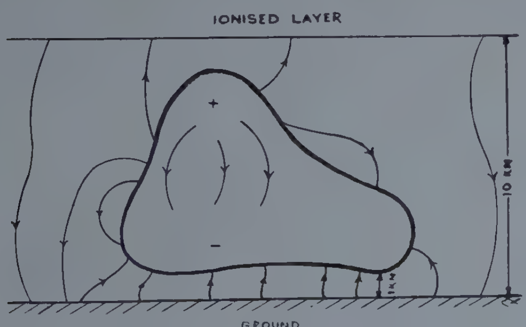


FIG. 1 — ELECTRIC FIELD UNDER THE CLOUD

TABLE I

No. of stokes	Height (km.)
2	5·1
3	5·4
4	6·3
5	7·1
6	7·6
7-9	8·9
10-12	9·0

It takes about 0·03 sec. to drain the charge from 1 km. of cell height in order to give the next stroke. The first stroke to descend to earth leaves a conducting channel which is separately followed by each of a series of succeeding strokes. While many clouds are fully discharged only by 10 strokes or more (even 40 have been observed), the average number of strokes is between 3 and 6, but during the storm these cells recharge and in the course of time lead to new strokes. At an average a stroke carries about 20 coulombs charge. The strokes can take place to the ground or cloud-to-cloud, the latter being more in inter-air mass storms.

The electrical process which lowers the charge to the ground follows a complicated sequence of events involving a mechanism called 'leader strokes'. The first ground stroke from a cloud is initiated by a very slowly moving process called the 'pilot leader' which paves the way for a 'stepped leader'. The pilot leader is invisible at the distances involved and its path wanders in such a way as to lead to the crooked and forked paths of the final channel. In general it takes between 2 and 20 millisec. for a stroke from the cell base at 4 km. to advance to ground. The illuminating stepped leader advances over the 10-200 m. of already ionized pilot leader channel at a speed of around 5×10^8 cm./sec.

When this ionizing channel has reached within 10 m. of the earth, it is met by an upward positive streamer which closes the gap and leads to the blinding flash of the return stroke.

The potential wave of the latter is a very violent and exceedingly rapidly moving pulse of high luminosity that travels as a potential gradient up to ionized path left by the leader stroke. Incidentally the phenomenon of the return stroke appears to be common to most electrical sparks.

After the events which have been described some time elapses until the potential at the cloud and of the channel rises to a point sufficient to reignite by a new leader process the now decayed path of ionization left by the previous stroke.

The charge lowered to earth from cloud by the first stepped leader may be about 4-5 coulombs. The average total charge per stroke is around 20 coulombs, but strokes carrying up to 160 coulombs have been observed. The current involved in the pilot leader and the stepped leader may amount to 50-60 amps. The return stroke builds a channel which carries currents as large as half a million amperes, but the average current is probably in the range between 5000 and 30000 amps. with the peak current lasting only 100-1000 μsec. After this heavy discharge has passed the channel remains luminous for some 0·2-0·5 sec.

The electrical potentials of the charged cloud masses are not known, but it was estimated that the gradient in the stepped pilot leader channel is about 1000 volts/cm., thus for 6 km. of path this would correspond to a negative potential to ground of about 600,000,000 volts (600 millions). Other estimates based on ion densities confirm the above figures and the cloud potentials may range from 680 to 2400 million volts.

Regarding the power developed by the lightning strokes it may amount to as much as $2{\cdot}4\times10^{11}$ kW. If such a stroke lasted for a millisecond the energy liberated would be $1{\cdot}3\times10^{5}$ kWh. Approximately only 1·6 per cent of the energy of the stroke would be required to ionize completely the gas in the column carrying the lightning and rest of the energy is liberated as frictional heat in the movement of gaseous ions through the gas. In case of an active thunderstorm cell as much as 200 flashes each delivering 20 coulombs may take place which corresponds to $2{\cdot}5\times10^{6}$ kWh of electric energy.

The heating of the channel of discharge produces an adiabatic expansion which creates a shock wave responsible for the characteristic sharp crack of the lightning. The atmospheric oscillations give rise to the intense low frequency rumble we call thunder. Considering the magnitude of the energy expended in an average lightning stroke (10^4 kWh) the sound produced is not particularly impressive as compared with firing of a gun. For instance, a 16 in. gun liberates only 2000 kWh of energy in a concentrated explosion which can be heard for about 30 miles while thunder ordinarily cannot be heard at distances above 12 miles.

The lightning stroke can produce fairly destructive results: it can volatilize copper wire at least up to 12 SWG, fuse an iron rod ¼ in. diameter and collapse a square tube 2×2 cm. by magneto-strictive action. The reason that more extensive destruction is not produced by heavy strokes probably arises from the circumstances that the current of the stroke is dissipated by a number of conducting paths at the ground end of the channel carrying the stroke, also the rate of change of current is so high that the inductance even of a straight conductor becomes important.

Isoceraunic Data and Outages of Overhead Lines

Frequency of Thunderstorms and Lightning Discharge — Statistics of storms throughout the world are now being collected and studied by the World Meteorological Organization, Geneva, and a full report on this work is to be published shortly.

The thunderstorm incidence is very variable in a given territory but over a period of years the average frequency seems to be constant in a particular region.

The lightning frequency in any place is related to the *isoceraunic level* the definition of which is the number of days in a year on which the thunder is heard in that region. This is, of course, not an accurate measure of the actual frequency of the lightning strokes to earth, but till now no better reference magnitude has been suggested. The main difficulty is the unknown proportion of the number of inter-cloud to ground strokes, both producing the sound of thunders. Nevertheless, a rough rule is that in temperate zones the number of cloud-earth strokes per square mile per year is half the isoceraunic level for the area concerned and in the tropics it is one-third.

It seems that in India the isoceraunic level is generally from 20 to 35 with the exception of the extreme south (Cape Comorin) and Assam-Bay of Bengal regions where it is 35-75. Since the truly tropical storms are generally an exception in this country the rule for temperate zones is more likely to apply.

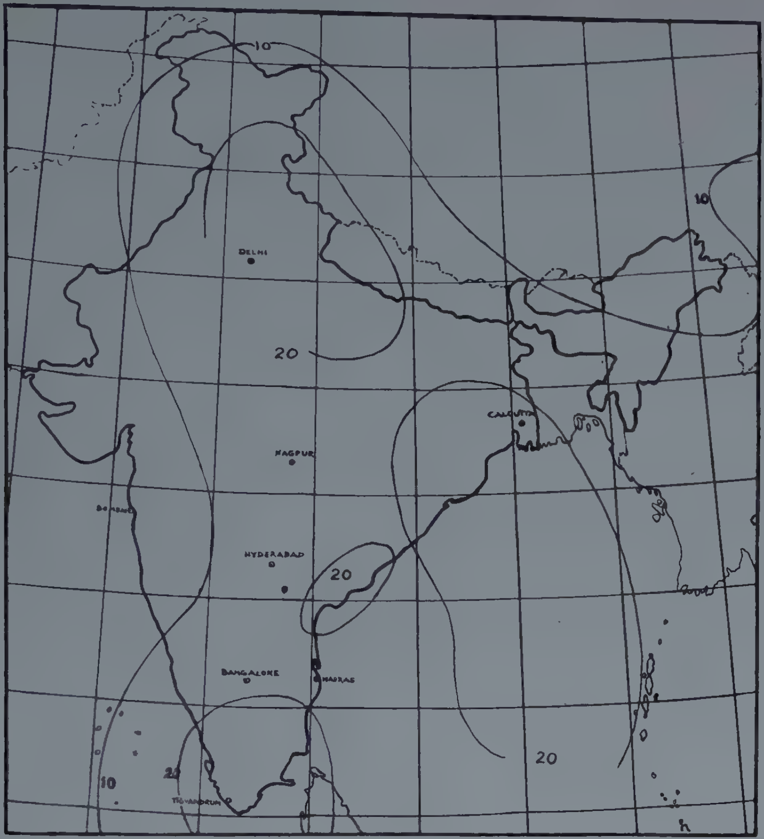


FIG. 2 — ESTIMATED NUMBER OF LIGHTNING FLASHES TO GROUND PER SQUARE MILE PER YEAR

The map of India (FIG. 2) shows in more detail the zonal distribution of the estimated lightning flashes to ground per square mile per year. Please also refer to Table II.

The records given in Table II are not complete and much remains to be done to collect reliable information in respect of the lightning frequency in this country.

Frequency of Lightning Stroke to Overhead Lines — The lightning stroke from cloud to ground may affect the overhead line indirectly by the sudden collapse of the electric field under the cloud or directly, if the lightning actually hits the conductor or the tower. This will be discussed with more detail in following section, the point which arises, however, is how to correlate the isoceraunic level of the terrain to the probability of lightning strokes to the line.

Here mention can be made of two methods generally used for probable stroke-to-line frequency calculation.

A.I.E.E. COMMITTEE METHOD — It is based on the assumption that the number of

TABLE II — NUMBER OF LIGHTNING FLASHES TO GROUND PER SQUARE MILE PER YEAR

REGION	NO. OF FLASHES
South Coromandal and Nicobar Isles	20
West Coast and Rajasthan	10
Sub-Himalayan Terai	20
Assam and Bay of Bengal	20
Eastern Ghats	20
The rest of India	5-10

strokes to a given length of line is independent of system voltage, etc., but directly proportional to the isoceraunic level, further that for an isoceraunic level 30 one stroke per mile of line per year may be expected and that the number of strokes which terminate at towers is equal to the number terminating at the mid-span. The above applies to lines provided with a single earth wire positioned to give shielding failures not exceeding 0·1 per cent.

E.R.A. Method — This method is based on a calculation of the area covered by the line using formulae derived from the theory of lightning discharges. For this purpose three types of transmission lines are considered:

(i) Line without earth wire
(ii) Line with one earth wire
(iii) Line with two earth wires

In each case the electrical area covered by the span is calculated (A) and if the span length is 'l' and isoceraunic level is 'Ω' then the lightning strokes to line per 100 miles of line per year (N) will be:

$$N=L(\Omega)A\times10^{-2}/l$$

where L is a factor assumed as L=1 for temperate zones and L=2/3 for tropics.

Other authorities on the subject assume that the lightning stroke frequency on the lines is proportioned to the isoceraunic level raised to a power somewhat greater than unity. Due to the variable nature of lightning average figures taken as a basis for calculation in the above methods produce large errors. In this connection the figures of survey conducted in U.S.A. on some systems are of interest (Table III).

It is clear from figures given in Table III that the frequency of strokes recorded fluctuates often within the limits of minimum number to maximum as much as one to four. In some years the frequency of outages due to lightning may be double or more of the average figure accepted for calculation.

TABLE III — LIGHTNING DATA ON TRANSMISSION LINES

System voltage	Circuit miles	Strokes per 100 miles per year	Year surveyed
220	91·8	59-129	5
132	33·8	86-219	5
66	52·2	66-232	4

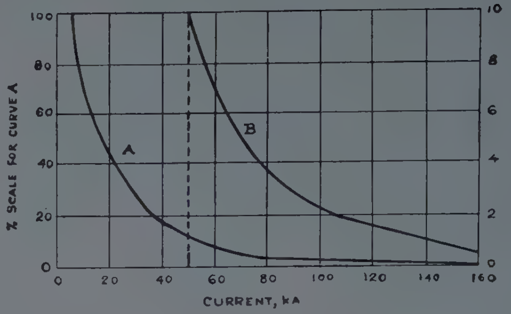


Fig. 3 — Currents in lightning strokes (curves give percentage of current values exceeding abscissa value with lower limit of 5 kA)

Lightning Response of Overhead Lines

Lightning is an important factor in establishing of a system trip out rate and in deciding the choice of arresters, reclosing breakers and other protective devices.

In considering the lightning performance of transmission lines the following parameters have to be determined:

(i) Waveform of lightning current surge
(ii) Magnitude of lightning current
(iii) Magnitude of voltage on the line

Waveform — Much information is now available from the actual records of wave shapes of lightning currents on transmission line. Recent investigations show that the front times are of the order of 2 µsec. or more, but probably at least 40 per cent of surges have front times from 0·5 to 2 µsec.

In general the waveform of lightning current surge when discharged through a lightning conductor is very roughly of double exponential form with a front time ranging from 0·5 to 10 µsec. and tails extending to 60 µsec.

Fig. 3 indicates the records of lightning current waveforms obtained by the actual field measurement. In Fig. 4 some typical oscillograms of lightning stroke current have been shown, collected by some American investigators.

The surge voltage impressed on line conductor has roughly the same wave shape as the lightning current discharged on it.

For the purpose of standardization of tests on lightning arresters certain definite wave

TABLE IV — COMPARISON OF TEST WAVES (μSEC.)

	I.E.C.	A.S.A.
Voltage	1×50	1·5×40
Current (duty cycle test)	8×20	10×20
Current (high current test)	4×10	5×10

shapes have been adopted by the International Electrotechnical Commission and American Standard Association. Table IV shows the comparison of test waves.

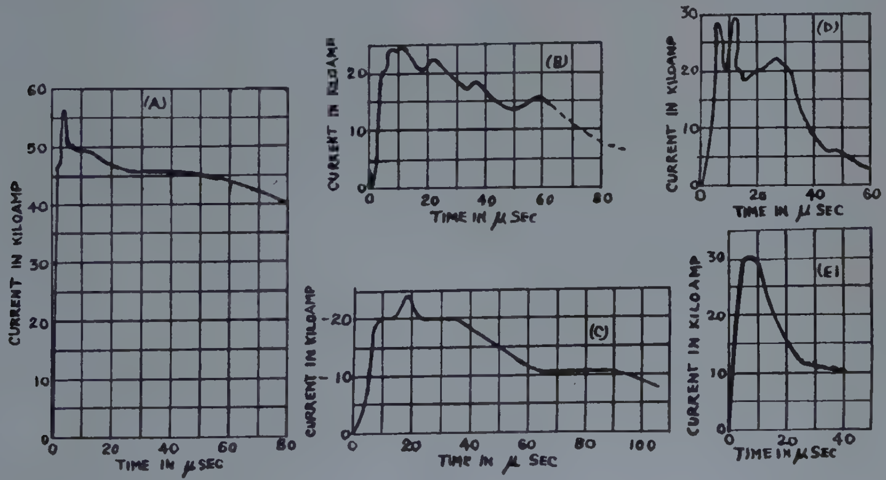
Lightning Currents — A considerable number of data is available regarding the stroke current crest magnitude. Most of this information was obtained by means of magnetic links. The A.I.E.E. has accepted probability distribution as indicated on Fig. 3. It can be seen that the minimum value of currents is at least 5 kA and maximum probably does not exceed 160 kA with a 50 per cent probability of 10 kA currents. This latter figure has, therefore, been accepted in most standards for rating of station type of lightning arresters in determining their duty cycle for 20 operations, but such arresters are also required to withstand a single high current test at 100 kA.

Surge Voltage of Transmission Lines: (i) *General Consideration* — The magnitude of the lightning overvoltage depends, of course, on the line construction and impedance. When an overhead line system is struck by lightning, the stroke may terminate on either a phase conductor, a tower or the earth wire, if provided. The crest of the initial voltage surge produced at the point struck will be equal to the product of the amplitude of the lightning current and the effective impedance presented by the path to earth. In case of the phase conductor or earth wire the current divides between two directions open to it and the surge impedance is usually about 250 ohms.

The surge impedance of the lightning arc channel created by the flashover may be about 5000 ohms.

If the lightning strikes direct a tower, the impedance presented is that due to the inductance of the tower in series with the tower's resistance, but the latter is often neglected.

The amplitude of the voltage surge produced at a tower either by direct lightning stroke or by a stroke to the earth wire at mid-span may be as much as 1 million volts or more and is therefore likely to produce a discharge over the insulation from the tower to a phase conductor known as a back flashover. The voltage surge on the phase conductor will then travel in both directions along the line and arrive finally at a station.



[A, B, C, Empire State Building$^{10-12}$; D, McCann^{2}; E, stroke to captive balloon^{13}]

FIG. 4 — TYPICAL OSCILLOGRAMS OF STROKE CURRENT

The initial effect of lightning stroke to a phase conductor is the same as that to an earth wire except that the insulators at the neighbouring towers will flashover before the current is discharged through the tower to earth. It is clear from the foregoing that the magnitude of lightning surge on the line will be determined by its insulation level, but in some cases may also have a higher value, this is due to the fact that the surge which reaches the neighbouring insulation is of steep wave front and owing to the breakdown time delay of insulators part of the original voltage may pass the insulators before they break down. Furthermore, the surges of opposite polarity will be reflected back from the flashover points and also the surge which fails initially to discharge through a protective device may have its amplitude doubled by reflection at the terminals of station apparatus of high impedance.

(ii) *Methods of Calculation*—Recent investigations of outages on 345 kV transmission lines in U.S.A. brought to light the shortcomings of the hitherto accepted methods of calculation of the lightning response of transmission lines. Certain new explanations of stroke mechanism such as ‘ corona burst ’ theory have been put forward recently, but further research is needed. In the past several methods have been proposed for calculation of the lightning surge voltages on the overhead lines, but two major obstacles are firstly an incomplete knowledge of the phenomena of lightning contacting a system and secondly over-simplified concepts of the response of a system struck by lightning. Four methods most in use will be briefly reviewed.

A.I.E.E. METHOD—This method assumes that the tower top potential is determined by the voltage drop across the tower-footing resistance plus certain amount of fixed inductance in the tower proper. The tower top voltage so produced is impressed across the tower insulator strings after having been decreased by an amount determined by capacitance coupling between the earth wire and the phase conductors.

SURGE IMPEDANCE METHOD—It treats the transmission tower as a short transmission line which has a certain surge impedance, fixed or variable, depending on the accuracy required.

Travelling waves of voltage and current are considered to move through this tower impedance and through the ground wires and sum up at the tower top to give the final voltage which is impressed across the tower string insulators.

ELECTROMAGNETIC FIELD METHOD — This method using Maxwell's field equations is basically analytical method involving establishing of valid boundary conditions of charge and voltage on the system. The problem is not simple and the calculations involved are very laborious; but many difficulties can be solved by the introduction of the electromagnetic geometrical model similar to that used in solution of antenna problems. Such models are usually reduced in size to 1/30 that of the original tower for laboratory surge studies.

COMPARISON METHOD — The comparison approach compares a line to be calculated with a standard line on which the lightning experience and outage rates are accurately known. This is mainly an extrapolation of experience and it demands a clear concept of the process which produces lightning voltages on the lines. A better knowledge of lightning phenomena and of electromagnetic behaviour of lines and towers is required before the method can be applied to best advantage.

Experimental Investigations of Surges on Transmission Lines

Need for Research — Although some intensive investigations have been and are being conducted in many transmission systems abroad, the conclusions reached may not be necessarily applicable to the transmission lines in this country for variety of reasons, such as difference in isoceraunic levels, topographical features of the terrain and soil characteristics, different design of towers, insulators, etc. It would therefore be highly desirable to formulate a programme of experimental investigation of high voltage and high current phenomena on the electric systems in India by making wave shape and amplitude records of rapid surges due to lightning. This field research could perhaps be conducted under the auspices of the recently created Power Engineering Research Organization under the Central Water & Power Commission (Power Wing). There are at present several types of instruments which could satisfactorily be used for such records.

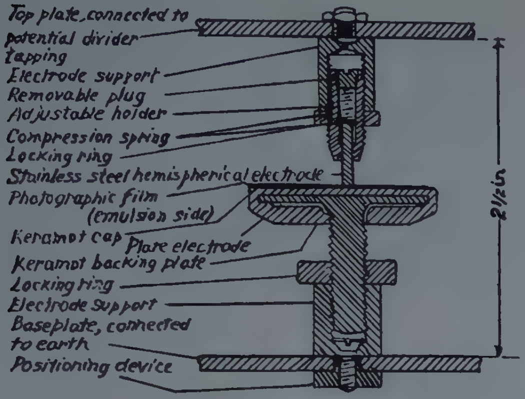
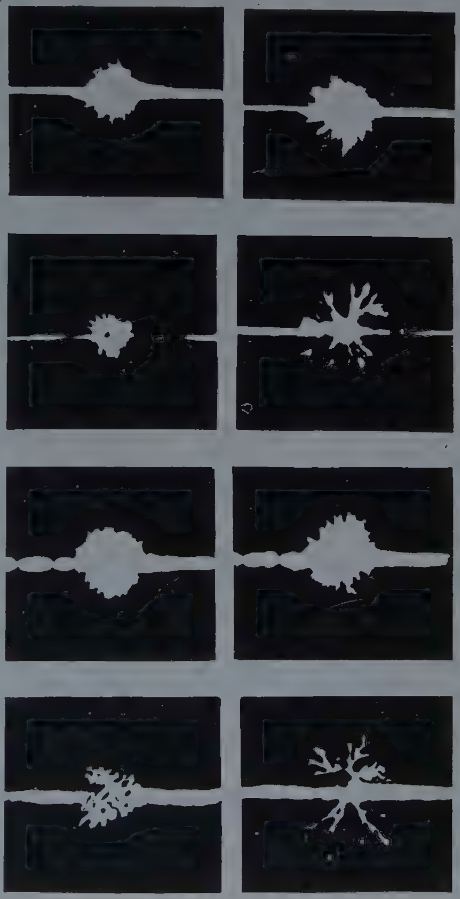


FIG. 5 — SECTIONAL VIEW OF NORMAL ELECTRODE PAIR IN KLYDONOGRAPH

Cathode Ray Oscillograph — Perhaps a most accurate but also most expensive method of investigation of transients on the lines is by means of cathode ray oscillographs. However, these instruments require frequent servicing, photographic recording, moving film mechanism and complex electronic circuiting. Another difficulty is that the lightning surges may be required to be recorded in localities where no low voltage power supply is available for oscillograph.

Klydonograph — While it is recognized that the oscillograph provides the best way of recording the surges, need also exists for a simpler and cheaper passive device that requires no power for its operation. Some fairly good devices have been developed for this purpose, among these is the *Klydonograph* in which use is made of the patterns known as Lichtenberg figures (after the name of a German scientist who discovered the phenomenon in 1777). These figures are produced on a photographic sensitive film or paper by a surface corona discharge. The general construction of the device is shown in Fig. 5. The Klydonograph may be used with a resistance shunt to measure a current surge or a potential divider to measure a voltage surge. Unfortunately, the records provided by this instrument give only one Lichtenberg figure at a time and the accuracy of the technique is generally considered to be no better than about ±25 per cent of peak voltage measurement. The appearance of Lichtenberg figures obtained is indicated in Fig. 6. From the nature of the figure registered on the film after development the polarity of the voltage surge can be deduced. The mean size of the figure depends mainly on the peak value of the applied voltage but is influenced also by the wave shape. It is usual for pairs of electrodes to be connected in parallel, one pair with a high voltage point and an earthed plate and the other pair with a high voltage phase and an earthed point. In this way both positive and negative figures are produced for each surge voltage (see Fig. 6).



[*Right*, reverse film, i.e. plane electrode at high voltage point electrode earthed; *left*, normal film, i.e. point electrode at high voltage plane electrode earthed]

FIG. 6 — KLYDONOGRAMS OF VOLTAGES ON TRANSMISSION LINE CONDUCTORS DUE TO DIRECT LIGHTNING STROKES TO THE TRANSMISSION LINE

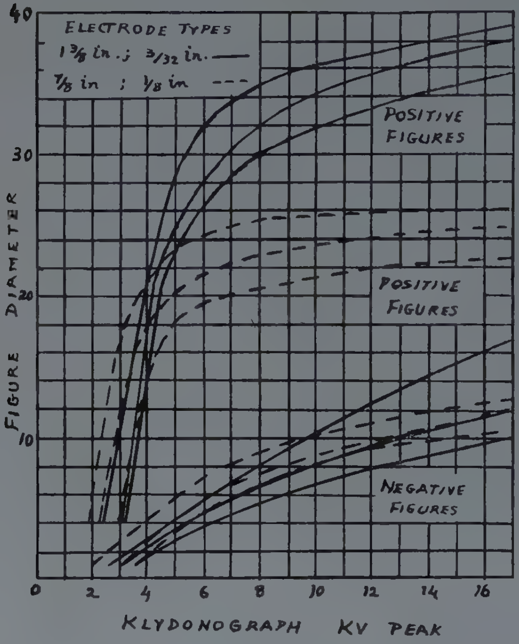


FIG. 7 — IMPULSE CALIBRATION CURVES CONNECTING FIGURE SIZE WITH PROBABLE, MAXIMUM AND MINIMUM VOLTAGES; TWO TYPES OF ELECTRODES; POSITIVE 1/50 μSEC. IMPULSES

The device is usually calibrated under laboratory conditions, for example, as shown by curves of Fig. 7.

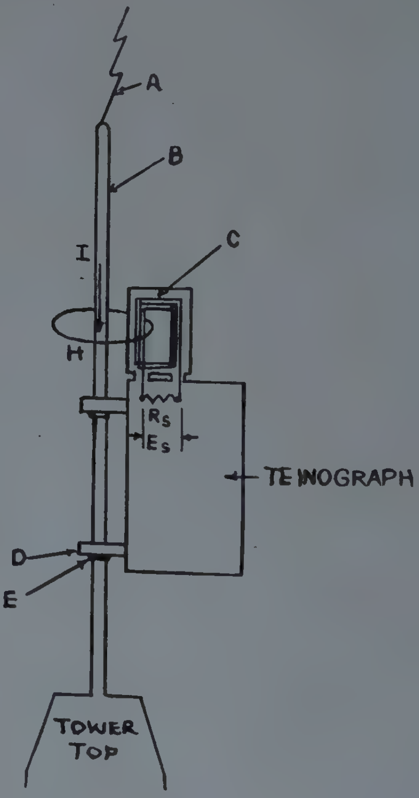
Klydonographs give necessarily rather inaccurate records, nevertheless due to their simplicity and low cost hundreds if not thousands of them have been used for measurement of lightning surges on transmission lines since 1924 till the introduction of perfected models of oscillograph. After 1936 the Klydonograph fell into oblivion but may come into use again in a modified version described later.

Magnetic Links — This device is used for the measurement of peak magnitude of the lightning current, but does not supply any information concerning the variation in time of the current pulse. Its essential feature is a packet of wires or strips of chromium carbon or any other steel alloy possessing high magnetic retentivity, placed in a glass or plastic tube filled with paraffin wax. The link is mounted at a known distance from the transmission tower or conductor, at a right angle to it. After the lightning discharge the link is removed and the residual magnetism measured by means of a ballistic galvanometer. This enables the peak value of the current carried by the neighbouring conductor to be calculated.

Some perfected devices using a series of links in combination with a rotating wheel such as ' fulchronograph ' or links with inductance coils and capacitors such as ' surge integrator ', etc., have also been developed by some research workers, but they are relatively more complex instruments.

A great deal of data have been obtained by means of magnetic links which continue to be used as a simple and reliable device for the measurement of peak values of lightning current surges.

New Instruments — Recently two new instruments have been developed which are a



[A, lightning stroke; B, lightning rod; C, pick-up coil in weatherproof housing; D, insulated bracket; E, supporting ring]

FIG. 8 — TEINOGRAPH OPERATION ON TOWER LIGHTNING ROD

revival of an improved form of the original Klydonograph inasmuch that they provide multiple records of surge by sequence of Lichtenberg figure discharges.

One such instrument is called 'Kino-Klydonograph' and the other 'Teinograph'. Preliminary tests show that these instruments have considerable promise and field tests are now in progress to gain further experience. Detailed description of these devices is not possible in this paper, but it suffices to say that the lightning current is picked up from the tower or a lightning rod by means of a coil and transmitted on to the circuit of capacitors and inductances with a number of discharge electrodes acting on a photographic film mounted on a base metal plate. By a combination of elements of the circuit it is possible to obtain either time sequential or space sequential record of Lichtenberg figures. The latter are then analysed and a curve on conventional co-ordinates traced to represent the amplitude of the phenomenon in function of the time.

The fundamental circuit of 'Teinograph' is indicated in Fig. 8.

The above new instruments described are still in the experimental stage and not available commercially, but the preliminary research on lightning surges in this country could very well be done by the time-proved devices such as the Klydonograph and magnetic links. Both these instruments can be manufactured indigenously in sufficient numbers, as they are very simple and cheap to make.

Conclusion

The thunderstorm is a natural phenomenon which has frightened and impressed man since the dawn of civilization. Although one important aspect of thunderstorms has been partly understood ever since Benjamin Franklin identified the lightning stroke as an electric spark, the thunderstorm is still an awesome, obscure and destructive phenomenon. In recent years experimental research conducted by means of a perfected Boy's camera mainly by Schonland, Collin, McEacheron and others brought forward much information leading to a better understanding of the stroke mechanism. Electrical engineer's interest in the thunderstorms and lightning lies in their effect on transmission lines and substation apparatus as it continues to be the most severe cause of outages on the lines. In many countries abroad, the field research regarding the effect of lightning was started in the early twenties when the first power transmission networks made their appearance.

In India the electricity supply industry is being given a very high degree of priority under the development programmes. Consequently the length of overhead lines also increases rapidly. Thus in 1955 there were in all about 55,000 circuit km. of overhead transmission lines with a highest voltage of 132 kV, but at present the total length of overhead lines is about 120,000 km., i.e. more than double. Also very soon the first transmission lines at 220 kV are expected to be commissioned. Although the various electric systems are being developed at present on the regional basis in various states, it is expected to interconnect them in future by a super-grid of possibly 400 kV.

Another important fact is the extension of areas covered by the transmission lines into new regions where very severe lightning conditions are known to exist such as Assam, Sub-Himalayan Terai, Nilgiris, etc.

So far no experimental field research of any kind has been done in India in respect of lightning response of transmission lines or even a systematic investigation of isoceraunic levels and lightning stroke density has not been conducted although some scanty information is available. Both the operating engineers and the manufacturers of electrical equipment and apparatus in this country have no data at their disposal to determine the most suitable insulation levels or to choose the best lightning protective devices. All decisions on problems relating to the lightning performance of lines and impulse level of apparatus and gear are taken in the dark or are based on the existing practice abroad which is not necessarily applicable to the conditions prevailing in this country. The main objective of this paper is, therefore, to bring forward the acute need for initiating the field research on lightning problems in India which should be done with the co-operation of all interested parties, i.e. electricity supply industry (public and private), manufacturers of transmission gear and apparatus, engineering research organizations and, of course, the Government.

Conference of Electrical Inspectors

THE Conference of All India Electrical Inspectors, the first of its kind since 1928, was held in Simla on 2 and 3 September 1960. Shri Jaisukh Lall Hathi, Union Deputy Minister for Irrigation and Power, inaugurated the Conference. Shri Hathi said that the Electrical Inspectors played a pivotal role in the scheme of administration of the Indian Electricity Act and the Indian Electricity Rules and further added that their experience would be extremely valuable for making progressive regulations for the safety of life and property against the electrical hazards consistent with efficiency and economy in giving power supply to the public. He expressed that a conference of this nature provides the Government with valuable suggestions based on the actual working experience for improving the electricity legislation to suit the changing needs of the times.

He pointed out that in 1937 a statutory organization called the Central Electricity Board was created under the Indian Electricity Act, 1910, with powers to make rules for regulating generation and supply of electricity and for carrying out the objectives of the 1910 Act. That Board had been periodically examining the rules and making amendments as and when found necessary. The Electrical Inspectors did not get an opportunity to meet after the constitution of such a Board to discuss their common problems, although they had in some cases been attending the Board's meetings as members and advisers. He felt sure that the Electrical Inspectors would make full use of the forum provided by the conference for discussion and interchange of their experience which would go a long way in bringing about uniformity of approach to the various problems in the states arising out of the administration of the Act and the Rules.

Shri Hathi then referred to the system of hot-line working, which had been introduced under the auspices of the Central Water & Power Commission. As the work involves great hazard, he suggested that the question of preparing a comprehensive safety manual for the use of the workers on hot lines may be considered.

One other important point which was suggested by the Deputy Minister was in regard to the question of inter-state recognition of the Electrical Supervisors' and Wiremen's certificates. He pointed out that although the Central Electricity Board had recommended common syllabus for these examinations, the system of reciprocal recognition of the permits and certificates issued by the authorities had not actually been in force in some of the states. He, therefore, hoped that the conference would give earnest consideration to the question of having a Central Board of Examiners for the purpose.

While concluding, the Dupty Minister referred to the D.C./A.C. conversion problem and said that the present position in regard to payment of compensation to the consumers for their equipment rendered obsolete by such changeover was not clear either in the Act or the Rules. He, therefore, felt that it would be desirable to examine the practice followed in the various states in this regard and to evolve a uniform formula for adoption and if necessary to draft out a suitable amendment to the existing statute to achieve the objectives.

In addition to clarifying the intentions of some of the provisions of the Indian Electricity Act, 1910, the Electricity (Supply) Act, 1948, and the Indian Electricity Rules, 1956, certain amendments were suggested to the I.E. Rules for consideration by the Central Electricity Board. A few important decisions taken by the conference are:

(i) The Electrical Inspectors should be entirely independent of the organization responsible for construction and maintenance of electrical projects, works, etc., but appointment of Electrical Inspectors may be made from the staff of the State Electricity Boards. It was considered that such a step would improve the inspectorial functions as the Inspectors would be directly in touch with the latest applications of electricity, and will be in full knowledge of the field conditions for exercising the statutory functions in an efficient manner and with a progressive outlook.

(ii) As 'caution' notice is required to be affixed on electrical generators, transformers, motors, supports of high and extra high voltage overhead lines, etc., and there was the the necessity to familiarize the same throughout the country, the work of standardizing the form of notice be entrusted to the I.S.I. in collaboration with the Central Water & Power Commission.

(iii) The Central Water & Power Commission should draft out a reference manual for hot-line working with particular reference to safety aspects.

(iv) The proposal for the appointment of the Central Board of Examiners for grant of competency certificates and permits to Electrical Supervisors and Wiremen should be examined for implementation on national basis.

(v) The practice of monthly drills should be introduced for training of staff in fire-fighting and restoration of persons suffering from electric shock.

(vi) The periodicity of inspecting the electrical installations was agreed to as under:

High and extra high voltage installations	Once a year
Medium voltage installations	Once in 3 years
Low voltage installations	Once in 5 years

(vii) The Central Water & Power Commission should evolve a standard form for making inspection reports on all India basis after examining the forms already in use in the various State Electrical Inspectorates.

(viii) The Central Water & Power Commission should frame recommendations in regard to the equipment to be provided and the work to be undertaken by the testing laboratories of State Electrical Inspectorates.

(ix) The Central Water & Power Commission should standardize the methods of construction for overhead lines for voltage up to 33 kV. It was felt that standardization of lines of higher voltage at this stage may not be desirable.

(x) The Central Water & Power Commission should evolve a suitable code dealing with the safety devices required for overhead lines.

(xi) The Central Water & Power Commission should evolve a standard design for oil drains and soak pits for oil-tilted electrical equipment and also for pole mounted substations.

(xii) It was decided that the Electrical Inspectors should furnish their proposals for the basis of compensation to be paid to the consumers for the equipment rendered obsolete due to D.C./A.C. conversion. This would be examined in the Ministry of Irrigation and Power with the help of the Central Water & Power Commission for formulating suitable provisions in the electricity laws of the country.

Progress of Power Projects

Damodar Valley Corporation

Bokaro and Durgapur Thermal Power Stations — The fourth unit (75 MW) at Bokaro was commissioned on 12 November 1960. Erection of the first unit (75 MW) at Durgapur is also complete and erection of the second unit is also nearing completion. The overall progress of the entire project has been 95 per cent.

Chandrapura Thermal Power Station — The preliminary works are in progress.

Transmission System — 132 kV transmission link to Jamshedpur is completed and 132 kV single circuit Maithon-Sultanganj line is completed up to 26 per cent.

Madhya Pradesh

CHAMBAL HYDRO-ELECTRIC PROJECT

Gandhisagar Power Station — The station was inaugurated by Honourable Prime Minister Sri Jawahar Lal Nehru on 19 November 1960. Two units (23 MW each) are in commercial operation.

Transmission System — Erection of 132 kV double circuit line from Gandhisagar Dam to Ujjain is nearly complete and final checking of 66 kV single circuit line from Ujjain to Ratlam has also been completed. The erection works on 66 kV double circuit line Ujjain to Indore and 66 kV grid substations at Nagda, Ratlam and Indore are in progress.

Madras

KUNDAH HYDRO-ELECTRIC PROJECT

The second unit (35 MW) at power house No. II was commissioned on 18 January 1961 by Mr. Gordon Churchill, Government leader in Canadian House of Commons. The erection of third unit has been completed up to 70 per cent and that of fourth unit up to 45 per cent.

Maharashtra

KOYNA HYDRO-ELECTRIC PROJECT

Erection of first main generator has been started on 7 November 1960. The assembly of rotor and stator is also in progress. Erection work on other units is also in progress.

Koyna-Bombay 220 kV Transmission Line — Excavation, stub setting and erection works on this line are in good progress. Fabrication of towers is also progressing at the factory of Kamani Engineering Corporation Ltd.

Orissa

HIRAKUD DAM PROJECT

Stage I — Erection of 66 kV substation at Betnoti is in progress and hydro power is being supplied from all the 132 and 66 kV substations except Betnoti 66 kV substation.

Stage II — Dewatering of power house pits and concreting for power house extension for fifth and sixth units at power house No. I are in good progress. Concreting for the power house No. II is also in progress.

Punjab

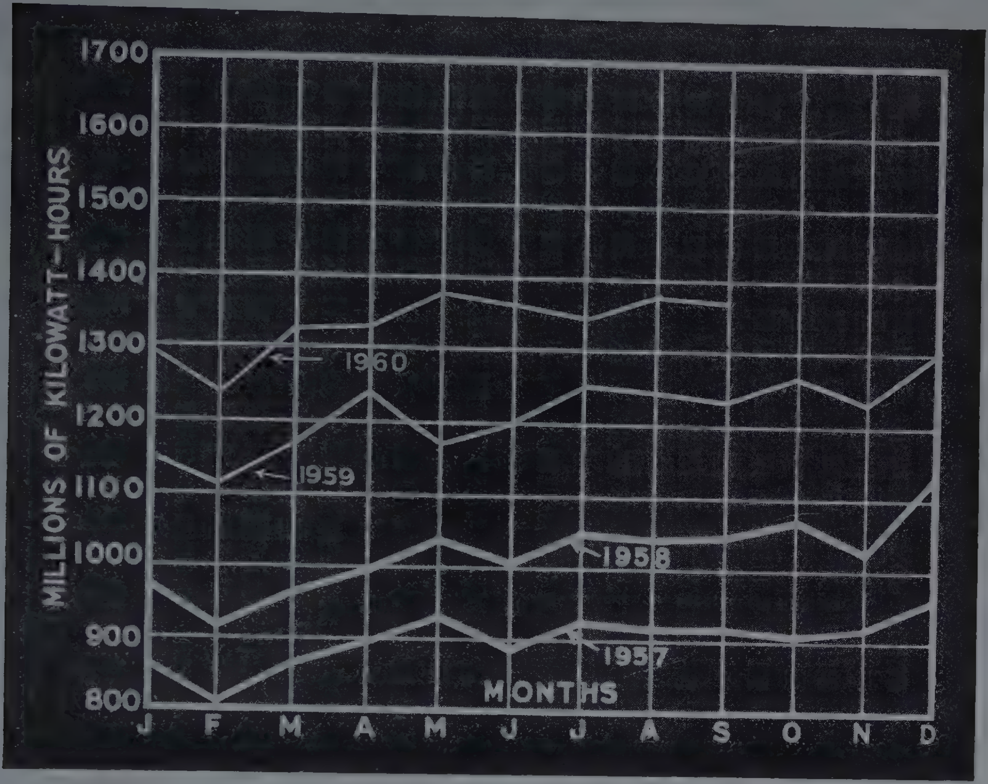
BHAKRA-NANGAL PROJECT

The first generating unit (90 MW) at Bhakra left bank power house was commissioned on 14 November 1960. The second unit was given its first trial run on 23 November and the balancing of the machine and other testing work was taken in hand. Erection work on other three units is also in progress.

Work on the erection of the third unit (29 MW) at Kotla and Ganguwal power stations is also in progress.

The material presented here has been made available by the kind courtesy of the *Central Water & Power Commission (Power Wing), New Delhi*

ELECTRICITY STATISTICS



ELECTRICITY PRODUCTION — ALL INDIA

OUTSTANDING FEATURES OF THE ELECTRICITY SUPPLY INDUSTRY, 1956 to 1958-59

	1956	1957-58	1958-59
Plant capacity (kW)			
Steam	1,596,412	1,763,257	1,879,553
Diesel	228,288	245,935	270,288
Hydro	1,061,441	1,213,919	1,361,745
TOTAL	2,886,141	3,223,111	3,511,586
Output (million kWh)			
Steam	5,133·900	6,042·454	6,847·644
Diesel	233·356	254·447	298·140
Hydro	4,294·877	5,072·241	5,848·102
TOTAL	9,662·133	11,369·142	12,993·886
Fuel consumption (metric tons)			
Coal	4,067,348	4,593,761	5,119,522
Diesel Oil	76,261	82,024	90,697
Maximum demand (kW)	1,989,744	2,288,212	2,542,955
Sales (million kWh)	7,959·345	9,430·097	10,718·610
Consumers*	2,825,802	3,207,508	3,617,844
Electrified towns & villages*	12,305	15,205	18,298

*At the end of the year.

MONTHLY PRODUCTION, 1959-60

MONTHS	kWh GENERATED (MILLIONS)			
	Steam	Diesel	Hydro	Total
October 1959	597·4	24·9	642·7	1,265·0
November ,,	623·3	23·8	587·0	1,234·1
December ,,	693·0	25·2	581·5	1,299·7
January 1960	678·1	25·3	591·1	1,295·5
February ,,	667·8	25·0	553·0	1,245·8
March ,,	708·3	24·7	585·5	1,318·4
April ,,	709·0	26·4	585·5	1,320·9
May ,,	738·1	25·1	617·5	1,380·7
June ,,	712·9	29·9	619·2	1,362·0
July ,,	679·7	30·2	633·3	1,343·2
August ,,	692·7	32·1	658·9	1,383·7
September ,,	668·6	30·5	666·4	1,365·5
TOTAL	8,169·9	323·1	7,321·5	15,814·5

The total electricity production for the twelve months ended September 1960 amounted to 15,814·5 million kWh, of which 51·7 per cent was generated by steam plants, 46·3 per cent by hydro plants and the remaining 2·0 per cent by diesel plants.

The above statistics have been made available by the kind courtesy of the *Central Water & Power Commission (Power Wing), Simla.*

Engineering Notes

Dungeness Nuclear Power Station

Work on the site began in August last year at Britain's sixth commercial nuclear power station at Dungeness on Kent coast. It is due to be completed in 1964. The Nuclear Power Group, a partnership between the Nuclear Power Plant Co. and A.E.I.-John Thompson Nuclear Energy Co., is building the power station.

Basically, the design of the reactors at Dungeness follows that of stations ordered earlier but also incorporates the latest developments in reactor and heat transfer technology.

The reactors will be of the gas-cooled, graphite-moderated type and use as fuel natural uranium bars clad in magnox sheaths.

The station is designed for a net electrical output of 550 MW and has two identical reactor units of approximately 840 MW thermal output each, a turbine house and the usual ancillaries.

Each reactor will have a prism-shaped, graphite core, made up of large octagonal and small square bricks, enclosed in a spherical steel pressure vessel. The vessel is surrounded by a primary biological shield of concrete through which pass the gas ducts to four boilers. Dry carbon dioxide at a pressure of 283 p.s.i.a. is circulated between the reactor core and the boilers by four blowers driven by back pressure steam turbines. Each reactor unit has its own control system, fuel store, on-load fuelling equipment and fuel cooling pond.

The turbine house will contain four 142·5 MW turbo-alternators. The steam and electrical connections between reactor units and turbine house will be taken underground through tunnels. The steam will be generated in the boilers at two pressures, 1418 and 590 p.s.i.a. All the higher pressure steam will be passed through the back pressure turbines driving the blowers. These turbines exhaust at the L.P. pressure and after reheating in the boilers, this steam is passed with the L.P. steam to supply the main turbines. The overall station efficiency when working at these conditions will be 32·9 per cent.

The station will be connected to the national grid (275 kV for connection to super-grid) in the same way as any conventional station. It will also be connected to the cross channel super cable at Lydd and across the channel to Boulogne.

A Goliath crane of 400 tons lifting capacity will be used to transfer both light and heavy parts of the reactor plant from the construction or delivery areas into the reactor areas. Heavy parts to be lifted include boilers, pressure vessel segments, etc.

TECHNICAL DATA

Performance	
Net electrical output	550 MW
Heat output per reactor	835 MW
Percentage efficiency	32·9
Reactor gas bulk outlet temperature	410°C.
Reactor gas inlet temperature	250°C.
Nominal max. can surface temperature	442°C.
Nominal max. uranium temperature	563°C.
H.P. steam pressure at blower TSV	1410 p.s.i.a.
H.P. steam temperature at blower TSV	392°C.
L.P. steam pressure at main TSV	550 p.s.i.a.
L.P. steam temperature at main TSV	391°C.
Feedwater temperature	180°C.
Fuel	
Number of fuel channels per reactor	3876
Number of elements per channel	7
Overall length of fuel element	41·7 in.
Dimensions of uranium rod	37·6 in. × 1·10 in. dia.
Total weight of uranium per reactor	298 tonnes
Core Dimensions	
Diameter of active core	45 ft. 4½ in.
Height of active core	24 ft.
Diameter of reflector	50 ft.
Height of reflector	27 ft. 10 in.
Lattice (square) pitch	7·75 in.
Gas Circuit	
Mean diameter of reactor vessel	62 ft. 6 in.
Reactor vessel general thickness	4 in.
Gas working pressure	283 p.s.i.a.
Number of gas circuit per reactor	4
Diameter of gas ducts	6 ft. 6 in.
Power input per blower	7 MW
Overall height of boilers	75 ft.
Internal diameter of boilers	23 ft. 6 in.
Shell thickness (graded)	3¾ in. to 2⅞ in.
Turbo-alternators	
Number of main turbo-alternators	4
Continuous maximum rating/set	142·5 MW
Speed	1500 r.p.m.
Generator voltage	13·8 kV
Vacuum	28·9 in. Hg.
Exhaust wetness	14·3 per cent
Total circulating water quantity	353,000 g.p.m.
Layout	
Distance between reactor building centres	426 ft.
Length of reactor building	316 ft.
Length of turbine house only	385 ft.

The Railway as Load

The development of the 50 c./s., 25 kV main line electrification system which is receiving close international attention is another tribute to the versatility of the British grid. Fundamental to the whole concept is availability of supply points for power infeed every 25-30 miles, reasonably close to the track, giving high supply security and sufficiently closely coupled with the overall transmission system to diminish by swamping the potentially troublesome effects arising from single phase rectified train loads. The lightly linked 132 kV grid meets these requirements so well that in most cases, it is thought unnecessary to take any special precautions about harmonics due to rectification (other than providing a delta winding to suppress the third harmonic) or against the unbalance introduced by concentrated single phase loads. Where main lines are supplied from 132 kV substation, no complex transformer connections are adopted, just single phase connection of single phase units, with adjoining sections supplied from different phases to limit unbalance. Such simplicity follows because the railway load is small as compared with general system load. The Euston-Manchester-Liverpool electrification will impose a maximum demand of about 110 kW and take 640 million kWh annually at a load factor of about 65 per cent. Even when freely developed including suburban and branch lines, the railway load is unlikely to exceed 3 per cent of overall system demand. (*Electrical Times*, 6 Oct. 1960)

Russia's Power Supply Programme

Russia's target for 1965 is 113,000 MW installed capacity, 90,400 MW thermal and 22,600 MW hydro. This involves commissioning an extra 43,880 MW of thermal plant and 9800 MW of hydro plant compared with the end of 1959. By the end of 1965, hydro should be providing 20 per cent of the annual generation of 500×10^9 kWh. Large capacity power stations are the basis of policy in Russia. Capacities of power stations are up to 6000 MW hydro and 2400 MW thermal plant and individual generating units are sized up to 500 MW hydro (design state) and 300 MW single shaft thermal units and possibly 800 MW two shaft. The 300 MW sets working at 3530 lb./sq. in. 1075°F. will be commissioned by the end of 1967. Excitation of large units is supplied by mercury arc rectifiers. The argument is that these provide fast and reliable operation and give good performance from the stability aspect when long transmission lines are being fed. The cost of rectifiers is reckoned to be less than for rotating exciters of comparable performance.

The use of concrete wherever possible to economize steel is one of the characteristics of 500 kV A.C. line and it employs prefabricated prestressed spun concrete structures in the forms of guyed towers. There is between 6 and 6·7 cu. yds. concrete in each structures and 2·1 tons of steel including guys. Wall thickness of the spun concrete is 1·6-2 in. Release clamps are used for the conductors permitting them to slip when the longitudinal load becomes excessive. (*Electrical Journal*, 4 Nov. 1960)

First U.S. Major Commercial Nuclear Generating Station Inaugurated

The commercially operated (Commonwealth Edison Co.) 180 MW nuclear generating station was inaugurated on 12 October 1960 at Dresden, Illinois. It is the first full scale privately financed nuclear power station in U.S.A. The reactor is of boiling water type and is the largest power reactor currently in service in America. The U.S. General Electric Co. undertook to build the Dresden plant for a fixed contract price of $45 million. Site and overhead costs of approximately $6 million has brought the total cost to about $51 million.. Commonwealth Edison Co., which owns and operates the plant, is paying $30 million of the contract price plus site and overhead costs. The $15 million balance of the contract price is being paid by the Nuclear Power Group Inc. as a research and development expense.

Faster Computer System

A new medium to large general purpose digital computer system is being introduced by the English Electric Co. Among its features is a very high speed of operation, with a main core store of 6 μsec. cycle time and multiplication in 14 μsec. cycles or less. Costing from £125,000 upwards, the first production model is scheduled for operation in 1962 and the company claim that it will be many times faster in operation than any machine now in use in this country without a comparable increase in cost. (*Electrical Times*, 13 Oct. 1960)

Major Relay Design Advance

A printed contact permanent magnet relay which makes possible substantial savings in space weight and assembly costs has been developed by the Components Division of Executone Inc. The new relay, known as Printact (registered trade mark), represents a new approach to relay, design and manufacture. The new relay is mounted on and becomes an integral part of a printed circuit board. Fixed contacts are eliminated entirely and the moving contacts which are part of the armature assembly are designed to match with conductors on the printed board. The new device employs a permanent magnet in place of a spring to hold the relay armature open. This force remains constant and eliminates any adjustment or maintenance. (*Electrical Engg.*, Nov. 1960)

Electrical Conductor Buses

A group of enormous aluminium tubes have been fabricated by the Delta-star Electric Division of H. K. Porter Co., Pittsburgh (Pa.), into what are believed to be the world's largest electrical buses both in physical size and in amperage capacity. For use as ' generator loads ' or ' station ' bus (to carry electric energy from a turbine generator into the switchyard of a power plant) the buses are 19 and 20·5 in. in diameter with $\frac{5}{8}$ in. thick walls. They are operated at 10,000-11,500 amperes for operation at voltages of 12·5 to 16·5 kV.

News of Current Interest

Symposium on "Integrated Operation of Hydro and Thermal Power Stations in India"

At the 32nd Annual Meeting of the Central Board of Irrigation and Power held at New Delhi on 21 November 1960, a symposium was held on "Integrated Operation of Hydro and Thermal Power Stations in India" wherein following five papers were presented:

1. Fixation of hydro plant capacity for deriving optimum benefits by Shri K. P. S. Nair, Member (Hydro-electric), Central Water & Power Commission, New Delhi
2. Interconnected operation of hydro-thermal stations in India by Shri S. Venkataramanan, Andhra Pradesh Electricity Board
3. Interconnected operation of thermal and hydro power stations by Sarvashri D'sa and Sambasiviah, Mysore State Electricity Board
4. A note on the possibility of establishing an all India grid and choice of voltage by Shri B. V. Deshmukh, Chief Engineer, Maharashtra State Electricity Board
5. Establishment of zonal grids — general principles and proposals for northern grid by Shri Harbans Singh, Punjab State Electricity Board

In his paper, Shri Nair discussed the importance of planning of hydro power stations on long-range basis for operation in a system including thermal power stations. Considering the several possible hydro-thermal combinations in India, running thermal stations at their maximum possible capacity and energy values, i.e. on system base load with hydro stations being assigned low load factor operations at the peaks of the system load, would afford more economic and justifiable co-ordination. The main benefit from the hydro-thermal combination is the increased system firm capacity and this system can be availed of only if the original designs incorporate the required facilities for such operations. He also stressed the need for forward planning of hydro power stations for operation in a mixed system. He also brought out the importance of daily load curves for fixing the plant capacity of hydro plants in such mixed systems.

Sarvashri Venkataramanan, D'Sa and Deshmukh explained in their papers the importance of interconnected operation of hydro and thermal stations and the need for system planning.

Shri D'Sa explained the importance of study of machinery characteristics beforehand including those of governors and voltage regulators. He also brought out the requirements of generator protection and importance of inertia of rotating parts in such a system.

Shri Deshmukh gave a general review of the power development in the western and central parts of the country and discussed the possible interconnection of power systems in this region.

In his paper Shri Harbans Singh brought out the possibility of establishing a northern grid interlinking the hydro systems of Bhakra, Ganga hydro grid, etc., with the thermal stations at Delhi, etc.

Second Power House of Kundah Switched on

Power house No. II in the Kundah hydro-electric project was formally inaugurated by Mr. Gordon Churchill, Minister for Veterans Affairs, Canada, on 18 Jan. 1960 at Ronning Town, 18 miles from Karamadai which is on the Coimbatore-Mettupalayam Road. He also inaugurated the extension scheme of the project.

Pressing a remote control switch Mr. Gordon Churchill started the power generators at Gedde, 10 miles away and also set in motion the blasting of rocks for excavation for the extension of the Kundah project.

The project — the sixth and the biggest power scheme to be launched in the state — when fully completed is to harness the waters of the Kundah river and generate a firm power of 343,000 kW with an installed capacity of 420,000 kW, in two phases, utilizing a head of over 5000 ft.

The total cost of the first and second stages of the project was Rs. 35·44 crores towards which Canada had contributed $23 million (about Rs. 11 crores) under the Colombo Plan aid. The third stage of the project is estimated to cost Rs. 23·06 crores.

Mr. Gordon Churchill in his speech announced that his government had now agreed to participate in the further developments — third and final stage — of the project by providing the essential equipment and services representing the foreign exchange costs totalling about Rs. 9 crores.

U.N. Special Fund Aid for Indian Projects

The United Nations Special Fund at its meeting on 21 Dec. 1960 has approved of a grant of $3·78 million for four projects in India. They are the Central Scientific Instruments Organization, Delhi; Cavitation Research Centre, Poona; National Aeronautical Research Laboratory, Bangalore; and Vocational Training Scheme for industrial trade.

The Fund has provided an allocation of $935,500 for the Central Scientific Instruments Organization with a counterpart contribution by the Government of India of $2·2 million. The Special Fund's allocation for this project will be spread over three years and is for the purpose of providing assistance to the C.S.I.O. in the design, development, standardization, testing and quality control of electrical, electronic, mechanical and optical instruments. The training programme is being provided under bilateral assistance. The Special Fund will provide a total of 24 specialists in electronics and in electrical, mechanical and optical instruments over a period of three years.

The Fund's allocation for the Cavitation Research Centre, Poona, is approximately $364,100, spread over three years and the purpose of the project is to supply and assist in installing a multi-test water tunnel for purposes of cavitation research on hydraulic structures and machines and to assist in training personnel in this field. The multi-test water tunnel which will be provided under the Special Fund assistance will have three or more test sections, equipped with measuring systems for head, discharge or velocity, water temperature, air content and pressure gradient control.

The purpose of National Aeronautical Research Laboratory is to assist in providing a scientific basis for India's growing aircraft industry and for the development of its potential in the aeronautical field, through conducting a comprehensive research and testing programme.

The Special Fund will provide over five years the equipment required for the transonic and supersonic wind tunnel, hydersonic tunnels, the air storage and wind power system including two 2500 h.p. compressors. It will arrange for the service of research specialists to assist in the installation and initial operation of the equipment and ten one-year fellowships to Indian personnel abroad.

Under its counterpart contribution the Government of India will provide full local currency capital and operating cost of the laboratory including professional and ancillary staff. At the end of assistance period, the laboratory is expected to be fully capable of carrying on its assigned programme of research and training.

The allocation for vocational training scheme for industrial trades of about $1 million is to assist in the implementation of the national vocational training scheme for industrial trade and I.L.O. has agreed to be the executing agency.

Bhakra's First Generator on Load

The first of five 90 MW hydro-electric generators has been put on load at Bhakra on 14 Nov. 1960.

Bhakra Dam, the world's highest straight-gravity dam (740 ft. high and 1700 ft. long) is part of the Rs. 170 crore Bhakra-Nangal project, an ambitious scheme which will eventually have an installed capacity of more than 1000 MW, as well as irrigating millions of acres of land. Besides the dam at Bhakra, which will store water for two power stations, another dam at Nangal supplies water for power stations at Ganguwal and Kotla. Both dams are part of the irrigation system. One of the Bhakra power stations is nearly finished and delivery of the five generators has been completed. Work has started on the other power station, which is being built on the opposite bank of the river.

Marine Radar 'Escort' Type 601

A new 'True Course' marine radar has recently been demonstrated by the A.E.I. Electronics Division. This new equipment, the B.T.H. 'Escort' type 601 manufactured by the Associated Electrical Industries Ltd., London, brings, for the first time, the science of the electronic computer to the aid of the marine navigator. This equipment is versatile and may be switched to present either

relative ship's head-up
relative azimuth stabilized
or true motion displays

It is entirely auto-aligning and automatic in operation so that the ship's officer may concentrate his attention on the radar picture without distractions and without the need to adjust, correct or reset the display.

Perhaps the most interesting feature of the equipment is the analogue computer, true motion generator which, while simple and compact, provides an outstandingly accurate true course display which is self-motioned and auto-correcting. It is entirely electronic and incorporates a number of new semiconductor devices also manufactured by A.E.I. Those silicon and germanium diodes perform the function of value rectifiers but have the advantage of being much more robust and reliable; having no heater electrodes, they greatly reduce the power consumption of the equipment.

The 'true course' generator is very versatile yet simple in operation and the difficulties which, in the past, necessitated a 'true motion' generator of electro-mechanical design have been overcome, and the limitations of mechanical techniques surmounted. By employing an analogue computer the manufacturers have provided a number of new features of great value to the mariner. When the azimuth stablized and 'true course displays' are used the North Point may be placed either at 12 o'clock or 6 o'clock on the display tube; thus the right-hand side of the display may always be set to represent the starboard side of the ship and the left-hand side of the diplay the port side of the ship, and this even when our own ship is proceeding on a southerly course. The true course display may therefore be used for pilotage under all circumstances without risk of confusion.

Kincardine Steam Power Station in Scotland

A new 1200 MW steam power station is being planned by the South of Scotland Electricity Board. It is intended that the station should draw its coal from the developing lothians coalfields and would be situated as near the pits as possible. Ultimate capacity of the station would depend on the amount of coal which the National Coal Board could make available. (*Electrical Times*, 13 Oct. 1960)

Wire and Cable Plant in Pakistan

The Pakistan Government have approved the establishment of a $6·5 million rod, wire and cable manufacturing plant by the American firm 'Phelps Dodge'. The plant will roll copper and aluminium into rod from copper wire bars and aluminium ingots respectively. Planned to have sufficient capacity to meet the entire requirements of the country, the plant will be built near Karachi and is expected to be in operation within a year. (*Electrical Times*, 13 Oct. 1960)

Federation of Electricity Undertakings — Annual Meeting

At the annual meeting of the Federation of Electricity Undertakings of India at Bombay on 28 January 1961, Hafiz Mohammed Ibrahim, Union Minister for Irrigation and Power, said that during the third five-year plan period it was proposed to add about 7·6 million kW to the existing generating

DR. S. RADHAKRISHNAN, VICE-PRESIDENT OF INDIA, AT THE TIME OF INAUGURATION OF I.E.C. CONFERENCE AT NEW DELHI

capacity raising it to 13·3 million kW at the end of the plan. In view of this extensive power development envisaged in the successive national plans, effective research on problems relating to power generation, transmission and distribution had become urgent. With this end in view, the Power Research Institute, which was being established at Bangalore, would not only be completed but also further expanded. A switchgear testing station would be established at Bhopal to meet the needs of the electrical equipment manufacturing industry. A specialized organization would be developed in the country to plan, design and construct large hydro and thermal stations. The development of the proposed organization would not only reduce the drain on foreign exchange but would also make the industry self-sufficient. More attention would be paid, than had been possible hitherto, to the interconnection of power grids, making the exchange of power possible, reducing the standby requirements and enabling the most efficient operation of the available plant.

I.E.C. Conference

THE Conference of the International Electrotechnical Commission (I.E.C.) was held in New Delhi from 30 October to 12 November 1960.

The twenty-fifth annual meeting of the I.E.C. in India was the first in the east. The meeting was inaugurated by Dr. S. Radhakrishnan, Vice-President of India.

The Commission has been at work for more than half a century. Its idea originated from the International Electrical Congresses held at the end of the last century, when electrical development was in its infancy and two years later, the first meeting of the Commission was held in London.

As most of the national committees of the Commission are closely associated with standards institutions in their respective countries, the closest liaison is maintained in the matter of setting standards for the manufacture and development of electrical goods.

At present nearly 40 countries are represented on the Commission, and there are nearly 100 committees dealing with various aspects of standard fixing.

The work of the Commission covers almost all spheres of electro-technology and is divided into two categories:

(1) Work for improving understanding between electrical engineers in all countries by drawing up common means of expression: unification of nomenclatures; agreement on quantities and their units, their symbols and abbreviations; standardization of systems of units and graphical symbols for diagrams.

(2) Standardization of electrical equipment proper, involving the study of problems of the electrical properties of materials used in electrical equipment, and standardization of guarantees to be given for certain equipment as to the characteristics, methods of test, quality, safety and dimensions controlling interchangeability of machines and electrical equipment.

The International Commission has been meeting every year since the end of the war, the last being at Madrid, Spain, in July last year.

At the New Delhi conference, several committees of the Commission met and took important decisions on standardization of electrical goods and techniques. These included radio equipment, high voltage switchgear and nuclear electrical instruments.

In the course of the conference, Prof. G. de Zoeten of the Netherlands delivered the Charles le Maistre memorial lecture on " The I.E.C. in an Expanding Electrical Technology and a Contracting World ".

Shri M. Hayath, Chairman, Central Water & Power Commission, has been invited to deliver the 1961 Charles le Maistre lecture at Internlaken, Switzerland.

Book Reviews

Indian Journal of Power & River Valley Development. Tenth Anniversary Special Number. Published by Shri P. K. Menon, 6-2 Madan Street, Calcutta 13. Pp. 156.

The publishers of the *Indian Journal of Power and River Valley Development* have brought out a very useful and informative issue of the journal to celebrate the completion of ten years of useful service in the cause of promotion and exchange of ideas on development of power resources and river valley projects in India. The special number of the journal which they have now published, besides containing very interesting articles from eminent engineers, scientists and economists of this country on various present-day topics on power and river valley development, also includes thought-provoking articles from top-ranking engineers from several leading countries like U.S.A., the Soviet Union, the U.K., France and Japan. We are sure that this publication will find a useful place in universities, technical institutions and engineering offices. Considerable effort and patient work must have gone behind the publication of this special number and the publishers have to be congratulated for adding one more special number to those already published.

C. S. S.

FBI Register of British Manufacturers — 1961. 33rd edition. Published in November 1960 for the Federation of British Industries by Kelly's Directories Ltd. and Iliffe & Sons Ltd. Price 50*s*. Post free.

The *FBI Register* is the directory of Federation of British Industries. It is comprehensive and accurate guide to a substantial cross-section of British industry, contains lists of the products and services of over 8000 member firms under more than 5400 alphabetical headings.

In addition to the classified Buyers' Guide, there are seven other sections in the Register, giving addresses of companies and firms and information about trade associations, proprietory names, trade marks, etc.

This recent publication would be useful to importers, buyers, trade commissioners, chambers of commerce, commercial attachés, reference libraries and departments of trade and industry.

University of Roorkee—Special and Refresher Courses

The University of Roorkee have arranged the following courses for the year 1961:

SPECIAL COURSES

	Period
Foundation Engineering	10 April to 6 May 1961
Earth Dams	17 April to 20 May 1961
Engineering Mathematics	13 May to 17 June 1961
Photo-elasticity	22 May to 30 June 1961
System Protection	1 to 30 June 1961
Foundry Engineering	1 to 22 July 1961
Economic Structural Design of Multi-storeyed Buildings	1 July to 30 September 1961

REFRESHER COURSES

	Period
Part I Transmission and Transformation lectures	1 August to 9 September 1961
Part II Generation lectures	1 to 31 October 1961

Tour common to both will be held from 10 *to* 30 *September* 1961

Further particulars for the courses may be had from the Director, Refresher Courses, University of Roorkee, Roorkee.

Society Activities

THE Annual General Meeting of the Society was held on 12 December 1960. The following is the text of Shri S. S. Kumar's Presidential Address read out on the occasion.

Presidential Address

BROTHER ENGINEERS,

I had been looking forward to attend the Annual General Meeting of the Society of Power Engineers today, but on account of the pressure of work, particularly in regard to the discussion with the State authorities on the proposals of power projects for the third year plan, which has kept us so busy that I regret my inability to be present amidst you today. I have, therefore, to content myself by sending the text of my speech to be read at the Annual Meeting and to extend my greetings to the members of the Society and wish them another important year of service to the profession of power engineers.

On this occasion I would like to touch briefly on the subject which may be uppermost in your mind, namely the accomplishments of the second plan and provision in the third plan for power projects. During the second plan provision was made for doubling the generating capacity from 3·4 million kW at the end of the first plan to 6·9 million kW at the end of the second plan. However, the recent indications are that we might touch the figure of 5·8 million kW only. This is considerably less than what was planned, due primarily to slowing down of some of the projects on account of foreign exchange difficulties. Thanks to many friendly countries who have come forward to help us by advancing loans to our Government particularly for many power projects under various aid programmes, it has been possible to take up implementation of many projects that had been earlier classified under 'non-core' category. It has been accepted on all sides that unless power is made available there can be no industrial progress. The country has been progressing very rapidly towards industrialization and we have to put all our energies together to see that the industry is not starved of power. Although I have to admit that there are complaints of power shortage everywhere, we hope to make it up during the third plan period. A target of 11·8 million kW has been tentatively agreed to by the Planning Commission, although this figure may increase after the plan proposals of all the states are finalized. The above figure includes the proposed 300 MW atomic station which is being located near Bombay where the coal costs are very high due to long haulage. Our country is fortunate in having vast deposits of thorium, perhaps richest known in the world so far, which provides a large reserve of nuclear power. More nuclear power stations are likely to come in the future in the areas distant from collieries where fuel costs are high and cheap hydro power is not available. One more source of generation of power has recently been found and that is the natural gas available in Assam oil fields, where four gas turbines of 16·8 MW capacity each will be installed during the third plan period.

As I have said already the main difficulty in progress of power projects is due to the large ratio of foreign currency component in the cost. To overcome this, it is proposed to manufacture generating equipment within the country itself. This has been appreciated and the capacity of the Bhopal Heavy Electricals Factory has been increased and they are likely to deliver the plants from 1962-63. In addition, two more similar factories are being planned during the third plan period. Another major problem that we engineers have to tackle during the third plan period is the interconnection of the grids to make the optimum use of the available generating capacity. It is estimated that at present only 3500 kWh are generated per kW of installed capacity. By interconnection of the grids this ratio can be improved considerably to compare with the Western countries.

In rural electrification it is estimated that about 19,000 localities will be electrified at the end of second plan as against 7400 localities by March 1956. The target at the end of the third plan has been set at 34,000 localities. Even then it would represent only about 6 per cent of the localities in the country. For this purpose, Rs. 105 crores have been provided during the third plan period.

The magnitude of the work ahead can be judged from the provision made in the third plan for power projects. the plan provides for an expenditure of Rs. 975 crores as against about Rs. 520 crores anticipated for the second plan, for both public and private sectors. This provision also includes Rs. 51 crores for the atomic power station and Rs. 24 crores for uranium mining and plutonium extraction plant.

Reverting to the affairs of our Society I am constrained to remark that I do not find much interest being taken in the Society as could be expected of the members perhaps due to pressure of work or otherwise. I was sorry to learn from my Executive Council that there was no response from members when nominations were called for various offices for carrying on the work of the Society. It should be our sacred duty to further the aims and objects of our Society and to promote the advancement of power engineering and to facilitate the exchange of information and ideas. This duty particularly devolves on the members posted at Simla who have been carrying on this onerous work since the very inception of the Society. I am sure the members will give a serious thought to this and volunteer themselves with all willingness and in greater number to shoulder the responsibility and the task involved in furthering the aims and objects of this Society.

I do not want to take more of your time, but before I close I must impress on all of you that this Society has to and can play a useful role in the national development programme of the country by holding discussions and contributing thought-provoking articles on the technical problems of the day. I appeal to one and all of you to put forth your best efforts, in whatever position you are placed, for the national good of the country.

Jai Hind.

REPORT OF THE EXECUTIVE COUNCIL OF THE SOCIETY OF POWER ENGINEERS FOR THE PERIOD 1 JULY 1959 TO 30 JUNE 1960

We have pleasure in presenting the Tenth Annual Report of the Society of Power Engineers for the period of 12 months ending 30 June 1960.

The audited accounts and the auditors report have been in your hands for some time and we are sure that you have gone through them and are satisfied with the progress made by the Society. Before we go into the details of the auditors report you will have noticed from the Balance Sheet that during the year under review the Society has made a net profit of Rs. 4638·87 increasing the toal capital fund to Rs. 37,263·44 as against Rs. 32,623·57 at the close of the last year.

You will have noticed from the accounts presented to you that the outstandings from the members towards their annual subscriptions amount to Rs. 9388·50 on 30 June 1960. It may be stated that Rs. 409·00 have since been collected. To this is to be added the outstandings from advertisers amounting to Rs. 10,641·75 as on 30 June 1960. This amount also includes advertisement charges booked for April 1960 issue of Power Engineer which was released only in September 1960. In view of the delay in the publication of the Journal the advertisement charges have not been recovered. However, it is gratifying to report that up to the end of November 1960, Rs. 4422·50 have been collected from the above outstandings.

It will be of interest to note that out of the assets an amount of Rs. 12,000·00 has been invested in the National Savings Certificates and a further sum of Rs. 5000·00 has been deposited with the bankers in the safe deposit account, which is bringing interest at the rate of 3½ per cent per annum. In view of the cash balances available, it has now been decided by the Council that a further sum of Rs. 5000·00 may be invested in the National Cash Certificates.

We would like to report to the General Body that although the printing charges of the Journal and the cost of paper have gone up considerably the selling price of our Journal to the subscribers has been maintained at Rs. 2·00 per copy. No increase in price is contemplated at present as the aims and objects of our Society are to promote the advancement of power engineering and allied subjects and their applications, particularly among the young engineers. Our Journal has been very much appreciated in the country as well as abroad and quite a number of requests have been received for supply of our Journal to various engineering societies and authorities interested on planning on exchange basis. This is being done. In addition, free copies

RECEIPTS AND PAYMENTS ACCOUNT FOR THE PERIOD 1 JULY 1959 TO 30 JUNE 1960

SOCIETY OF POWER ENGINEERS

Receipts

		Rs.
To Balance of cash and bank balances as on 30 June 1959		28,821·45
Subscription for Membership/Associate Membership/Associate/Student Membership		
1958-59	Rs. 1,324·00	
1959-60	... 3,566·00	
1960-61	... 452·00	5,342·00
Application fees		178·00
Bank charges		18·91
Suspense a/c		50·00
Total ...		34,410·36

Payments

		Rs.
By Printing and stationery ...		179·13
Entertainment		406·27
Establishment charges ...		1,110·00
Packing, postage and telegrams ...		817·60
Railway freight		441·30
Sundry disbursement ...		44·50
Contribution to Local Centres ...		212·50
Bank charges		90·96
Transferred to " Power Engineer " a/c		2,707·64
Cash in hand	Rs. 184·84	
Bank balances	... 11,104·37	
Fixed deposit	... 17,000·00	
Depreciation reserve	111·25	28,400·46
Total ...		34,410·36

" POWER ENGINEER "

Receipts

		Rs.
To Advertisement charges		
1958-59	Rs. 5,586·50	
1959-60	... 5,926·75	
1960-61	... 1,200·00	12,713·25
Journal subscriptions		
1959-60	... 1,474·50	
1960-61	... 1,268·77	2,743·27
Postage		11·31
Bank charges		18·24
Miscellaneous (sale of old copies, etc.)		1,119·87
Balance transferred from society's a/c		2,707·64
Total ...		19,313·58

Payments

	Rs.
By Printing of Journals	15,433·25
Reprints	378·94
Binding charges	405·50
Packing, postage and telegrams ...	1,068·24
Establishment charges ...	1,300·00
Printing and stationery ...	251·02
Railway freight	76·53
Sundry disbursements ...	68·38
Furniture and fixture ...	240·75
Bank charges	90·97
Total ...	19,313·58

(Sd.) S. K. Aggarwal
Treasurer

(Sd.) L. G. Thadani
Secretary

(Sd.) S. S. Kumar
President

(Signed as per the report of even date on the Balance Sheet.)

Simla
Dated 19 November 1960

(Sd.) B. S. Dua
Hony. Auditor

(Sd.) J. P. Misra
Hony. Auditor

of our Journal have been supplied to various educational institutions in the country to popularize our Journal. It is hoped this will bear fruit during the coming years.

Audit Report

No serious objections have been raised by the auditors who have inspected and certified the accounts of our Society. It may be stated against item 4 regarding the outstandings from members as well as advertisers, that active steps are being taken to collect as much as possible by personal D.O. letters to the members of the Society and personal contacts with the advertisers.

Budget

Budget for the year 1960-61 is placed for the approval of the General Body.

INCOME AND EXPENDITURE ACCOUNT FOR THE PERIOD 1 JULY 1959 TO 30 JUNE 1960

SOCIETY OF POWER ENGINEERS

Expenditure		Rs.	Income		Rs.
To Printing and stationery ...		179·13	By Membership subscriptions ...		8,672·00
Entertainment		406·27	Application fees		178·00
Establishment charges ...		1,120·00	Balance transferred from "Power Engineer" a/c		62·57
Packing, postage and telegrams ...		831·95			
Contribution to Local Centres ...		262·50			
Railway freight		441·30			
Depreciation of furniture, etc. ...		36·00			
Bank charges ...	Rs. 90·96				
Less received ...	18·91	72·05			
Miscellaneous expenses (labour, sundries, etc.)		44·50			
Bad debts written off ...		879·00			
Net surplus transferred to Balance Sheet		4,639·87			
TOTAL ...		8,912·57	TOTAL ...		8,912·57

"POWER ENGINEER"

Expenditure		Rs.	Income			Rs.
To Printing of Journals		15,090·26	By Subscription of Journals ...			2,743·72
Reprints		515·61			Rs.	
Binding charges		203·50	Advertisement charges			
Purchase of paper for			Gross		19,400·00	
Journal	Rs. 2,794·95			Rs.		
Less ...	1,300·00	1,494·95	*Less* A.C.	2,482·75		
Packing, postage and telegrams ...		1,082·60	*Less* discount	510·00	2,992·75	16,407·25
Establishment charges ...		1,300·00	Sale of old copies, etc. ...			1,131·18
Printing and stationery ...		251·02				
Bank charges ...	Rs. 90·97					
Less received ...	18·24	72·73				
Railway freight		76·53				
Depreciation on furniture, etc. ...		64·00				
Miscellaneous expenses (labour, sundries, etc.)		68·38				
Net surplus transferred to Society's a/c		62·57				
TOTAL ...		20,282·15	TOTAL ...			20,282·15

(Sd.) S. K. AGGARWAL
Treasurer

(Sd.) L. G. THADANI
Secretary

(Sd.) S. S. KUMAR
President

(Signed as per report of even date on the Balance Sheet.)

Simla
Dated 19 November 1960

(Sd.) B. S. DUA
Hony. Auditor

(Sd.) J. P. MISRA
Hony. Auditor

Membership

The membership of the Society now stands at 712 at the end of November 1960 as compared to 648 at the time of the last general meeting. In addition, 36 membership applications have been approved by the Council, but since the first subscription has not been received, these have not yet been enrolled as members and hence not included in the above number. Nine more membership applications are pending before the Council for approval.

BALANCE SHEET AS ON 30 JUNE 1960

LIABILITIES

	Rs.	Rs.
Subscriptions received in advance		
Membership subscriptions		452·00
Advertisement charges (net) ...		1,380·00
Journal subscriptions		1,268·77
Outstanding liabilities		9,811·56
Suspense a/c		68·00
Capital fund		
Balance from last year ...	32,623·57	
Add excess of income over expenditure during the year ...	4,639·87	37,263·44
TOTAL ...		50,243·77

ASSETS

	Rs.	Rs.
Cash and bank balances		
Cash and cheques in hand	184·84	
Cash at bank ...	11,104·37	11,289·21
Investment		
National Savings Certificate (at cost) ...	12,000·00	
Fixed deposit in the bank	5,000·00	
Depreciation reserve ...	111·25	17,111·25
Furniture and fixture (*at cost*)	1,906·06	
Less depreciation to date	368·00	1,538·06
Membership subscriptions outstanding		
Membership subscriptions	10,267·50	
Less written off ...	879·00	9,388·50
Advertisement charges outstanding (*net*)		10,641·75
Journal subscriptions outstanding ...		275·00
TOTAL ...		50,243·77

(Sd.) S. K. AGGARWAL
Treasurer

(Sd.) L. G. THADANI
Secretary

(Sd.) S. S. KUMAR
President

CERTIFICATE OF THE HONORARY AUDITORS

Having had access to all the books and accounts of the Society maintained by them in the course of their business and examined the foregoing statements and verified the same with the accounts and vouchers relating thereto, we now sign the same as found to be correct subject to our report of even date.

Simla
Dated 19 November 1960

(Sd.) B. S. DUA
Hony. Auditor

(Sd.) J. P. MISRA
Hony. Auditor

Meetings of the Executive Council

During the year under review seven meetings of the Council were held to transact the business of the Society. It may be mentioned that frequent meetings could not be held due to want of quorum, particularly since the office of the Punjab Electricity Department shifted from Simla to Patiala resulting in the transfer of five members of the Council. Since none of the members resigned from the Council, we could not co-opt any members from the panel approved at the General Body Meeting.

Activities of the Society

During the current year four meetings were held where technical films were exhibited. A meeting of the Society was also organized in September 1960 during the Conference of the Electrical Inspectors held at Simla and opportunity was taken to invite the Deputy Minister, Shri Jaisukh Lall Hathi, who gave a talk to the members.

Local Centres

You will be pleased to note that quite a number of activities were organized by our *Ahmedabad* Centre. Among one of the activities, members were taken round various power installations in and around Ahmedabad. Credit for these activities are due to the interest taken by the President and Secretary of that centre. It may be mentioned for your information that elections were held in October 1960 and the following office-bearers were elected:

1. SHRI K. N. PAULIN, *Chairman*
2. SHRI J. G. PATEL, *Vice-Chairman*
3. SHRI J. D. PANDIT, *Secretary*
4. SHRI M. N. SHASTRI, *Jt. Secretary & Treasurer*

We regret to report that the *Calcutta* Centre has not been able to organize any activity during the year.

The local centre at *Delhi*, which was set up during last year, was also not able to organize any activity.

Election of Office-bearers for 1960-61

In the General Body Meeting held on 22 December 1959 it was approved by you that the present office-bearers should continue in office till June 1960. In the normal course, therefore, the nominations for the various offices of the Society were invited in March 1960. We very much regret to say that the local members of the Society did not respond except for a few offices. It, therefore, fell to the lot of the Secretary to use his personal influence with some of the members to accept the various offices for which no nominations were received, to carry on the good work of the Society started ten years ago. The Council, therefore, requests the

BUDGETED INCOME AND EXPENDITURE FOR 1960-61

Expenditure	Rs.
To Printing of Journals	16,500·00
Block making	1,700·00
Reprints	400·00
Binding charges	220·00
Packing, postage and telegrams	2,500·00
Establishment charges	2,900·00
Entertainment	500·00
Remuneration to the authors of articles	400·00
Printing and stationery	600·00
Bank charges	200·00
Railway freight	550·00
Purchase of furniture and fixtures	500·00
Bad and doubtful debts	200·00
Depreciation	108·00
Contribution to Local Centres (Ahmedabad, Calcutta and Delhi)	500·00
Miscellaneous charges	200·00
Excess of income over expenditure	2,122·00
Total	30,100·00

Income	Rs.
By Advertisements	16,000·00
Sale of Journals	3,200·00
Membership subscriptions	9,500·00
Application fees	200·00
Sale of old copies of Journals	1,200·00
Total	30,100·00

General Body to confirm the election of those whose nominations were received and to approve the appointment of the nominees for the posts for which nominations were not received:

1. *President* — Shri K. P. S. Nair, Member (Hydro-electric), Central Water & Power Commission (His nomination duly seconded was received and he is elected unanimously as the President of the Society)
2. *Vice-President* — Shri C. K. V. Rao, Director, Central Water & Power Commission (He is also elected unanimously as there was only one nomination)

No nominations were received for the offices of the Secretary, Joint Secretary and Treasurer. We recommend the following names for the consideration of the General Body:

1. Shri B. S. R. Iengar, Dy. Director, Central Water & Power Commission — *Secretary*
2. Shri S. S. Sehgal, Asstt. Director, Central Water & Power Commission — *Joint Secretary*
3. Shri B. R. Dhawan, Asstt. Director, Central Water & Power Commission — *Treasurer*

With regard to the members of the Council, the following four members are elected unopposed against six vacancies:

1. Shri S. S. Kumar, Member (T. & A.), Central Water & Power Commission, who remains Member of the Council by virtue of retiring President as per the Bye-laws
2. Shri S. L. Rajeha, Distribution Engineer, Simla Municipality
3. Shri S. K. Aggarwal, Asstt. Director, Central Water & Power Commission
4. Dr. M. P. Varshney, Asstt. Professor, Kharagpur Engg. College

The following members are recommended for the two vacancies of the Executive Council:

1. Shri L. N. Nangia, Executive Engineer, H.P. Electricity Branch
2. Shri D. G. Shinde, Dy. Director, Central Water & Power Commission

The following names are recommended for the consideration of the General Body to be placed on the panel:

1. Shri B. Choudhury
2. Shri G. N. Rao
3. Shri Charanjit Singh
4. Shri B. N. Kapoor
5. Shri L. C. Pamnani

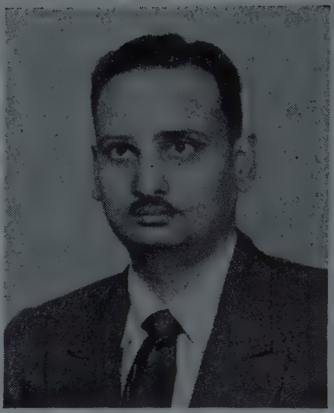
Auditors

According to the Bye-laws of the Society the auditors retire and the Council propose that Sarvashri J. P. Misra and B. S. Dua may be appointed for the year 1960-61.

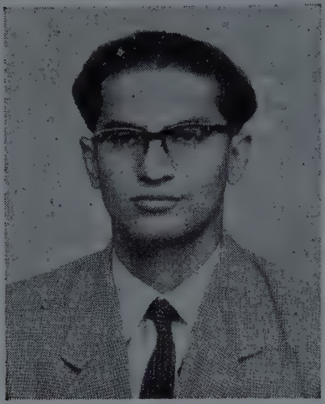
Acknowledgement

The Council takes this opportunity to express thanks for the services rendered by Sarvashri J. P. Misra and B. S. Dua who have audited the accounts and gave valuable advice and guidance for the maintenance of the books of the Society.

Personal Notes



Shri S. Vijayaraghavan, Assistant Director, Central Water & Power Commission (Power Wing) and an Associate Member of the Society of Power Engineers, recently visited the Soviet Union on deputation from the Central Water & Power Commission (Power Wing).



* * *

Shri C. P. Jain, Extra Assistant Director, Central Water & Power Commission (Power Wing) and an Associate Member of the Society of Power Engineers, recently visited the Soviet Union on deputation from the Central Water & Power Commission (Power Wing).

POWER ENGINEER — SPECIAL NUMBER

We have pleasure in announcing that a SPECIAL NUMBER of POWER ENGINEER will be brought out in April 1961 which will incorporate in it the usual April issue.

The SPECIAL NUMBER will commemorate the successful completion of the ten years by POWER ENGINEER.

The SPECIAL NUMBER will be devoted chiefly to the various aspects of power development in the Second and Third Five Year Plans.

The SPECIAL NUMBER will be issued in lieu of the subscription copy to regular subscribers. For casual orders, the price will be Rs. 4·00 per copy.

Orders for the SPECIAL NUMBER may please be booked in advance. Additional advertising space will also be provided for double colour printing. Clients are requested to apply for additional pages required.

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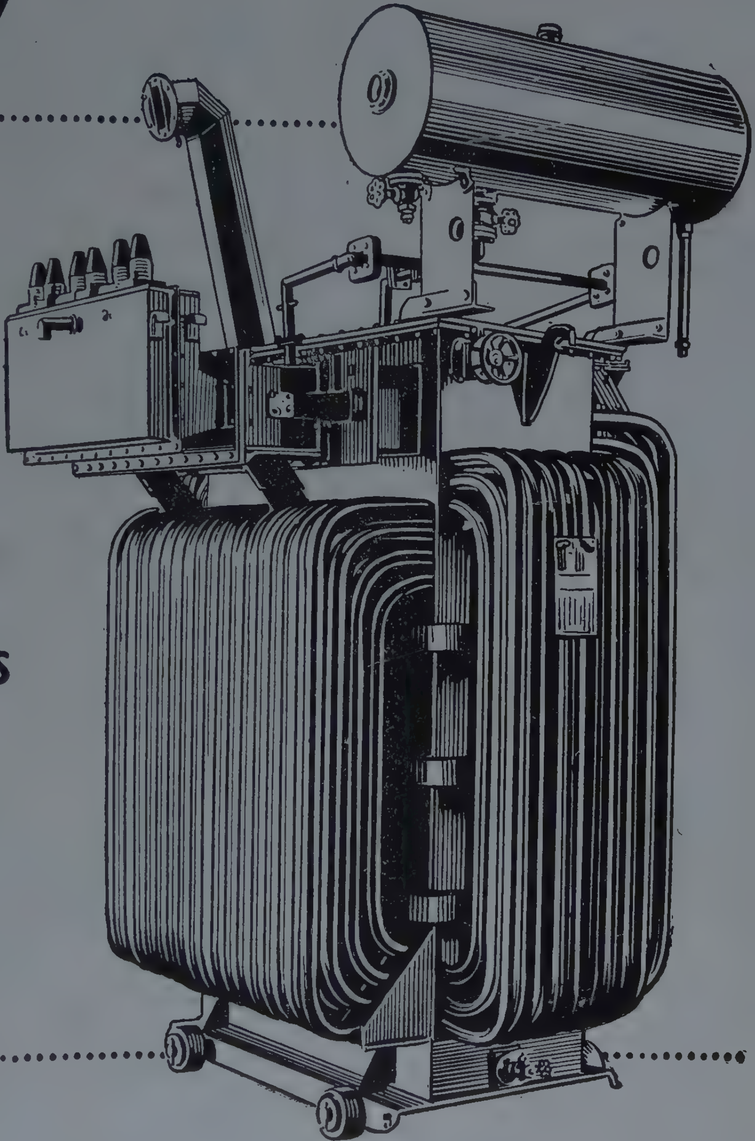

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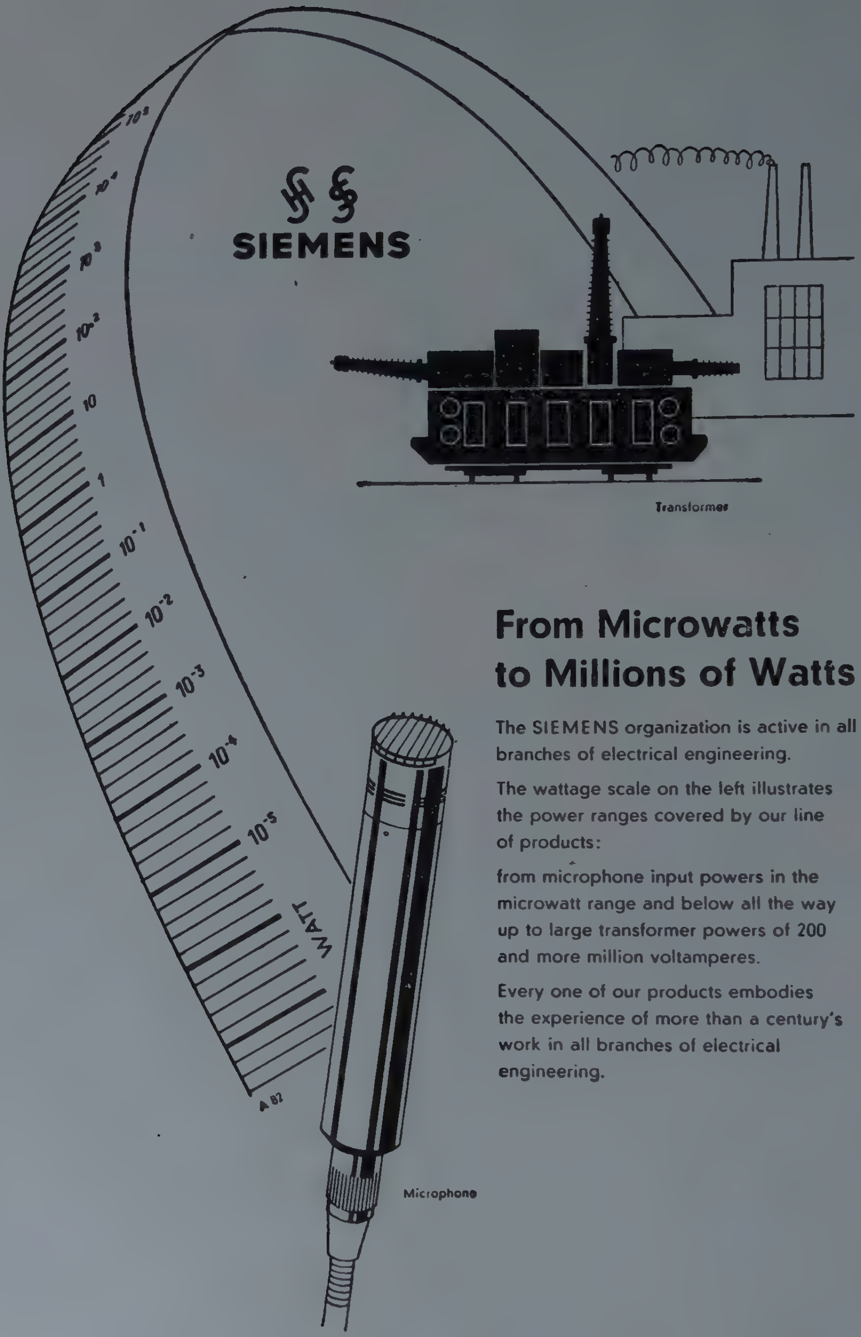

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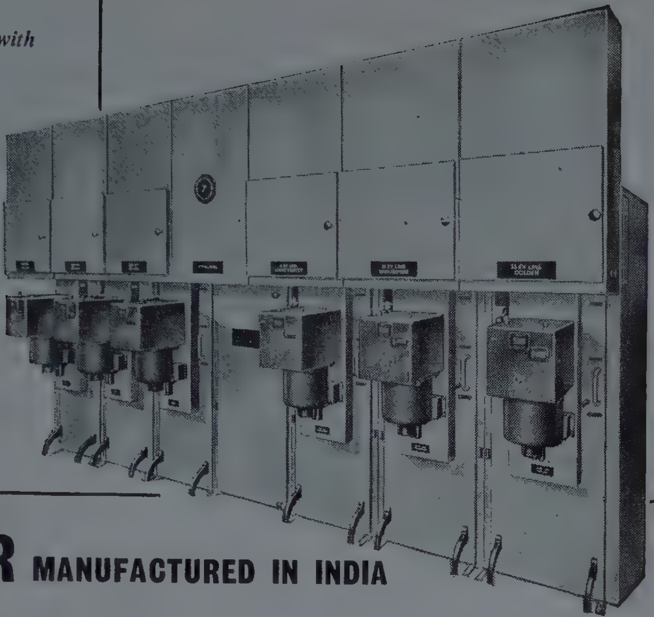

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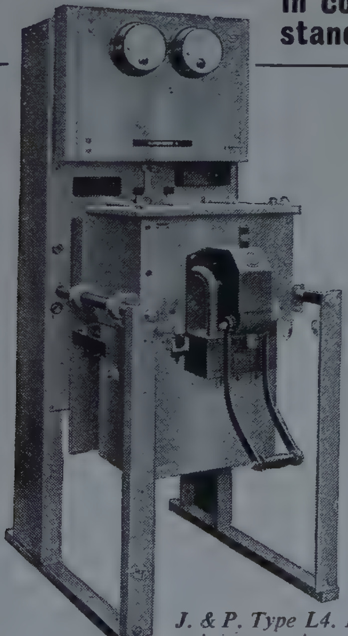

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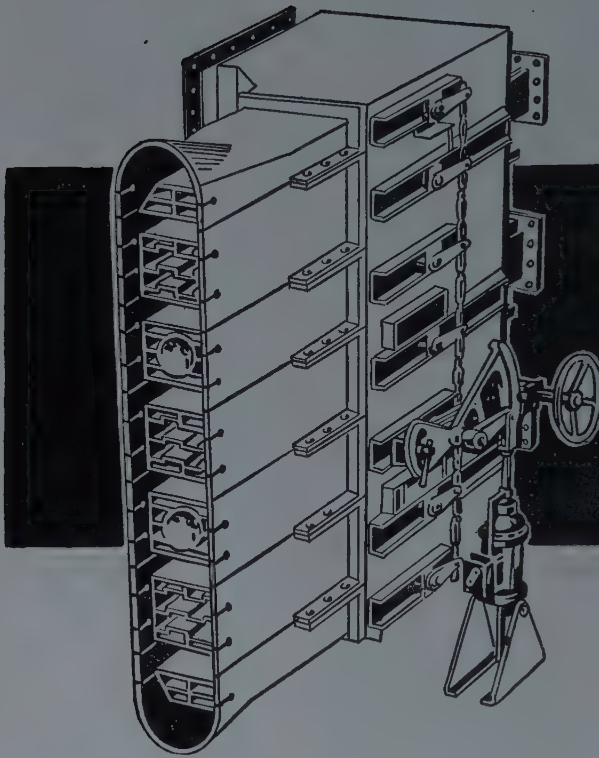

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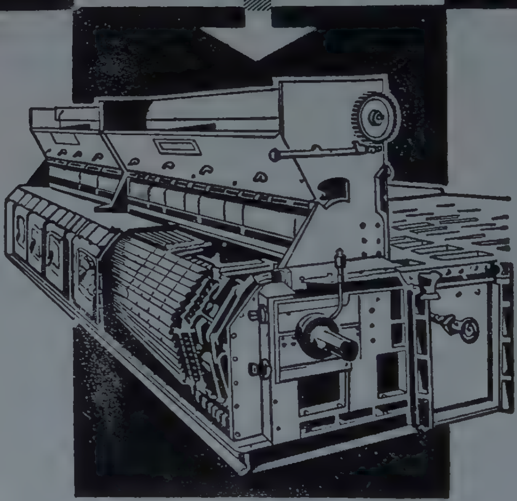

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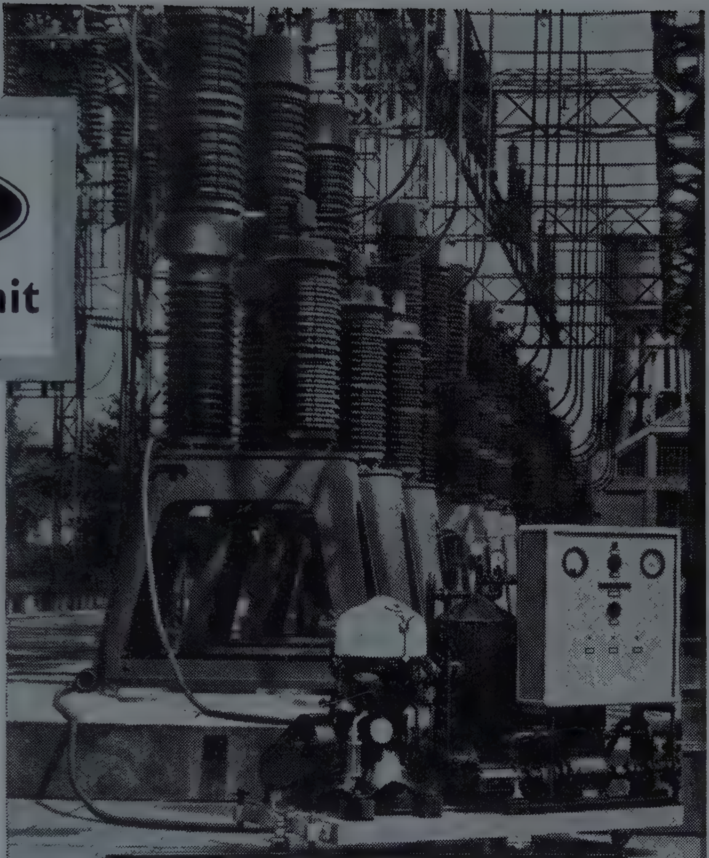

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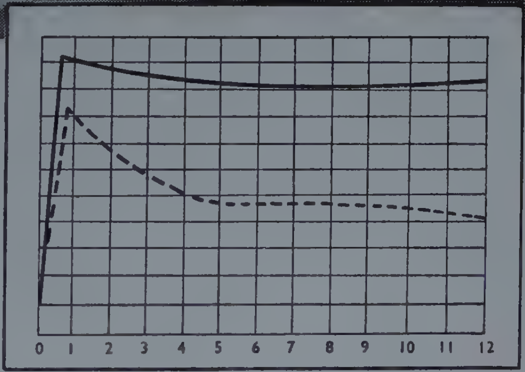

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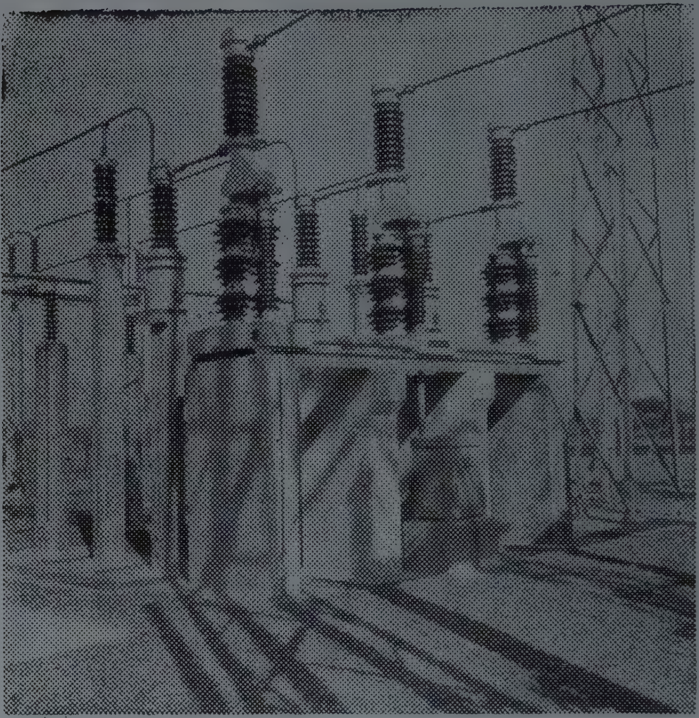

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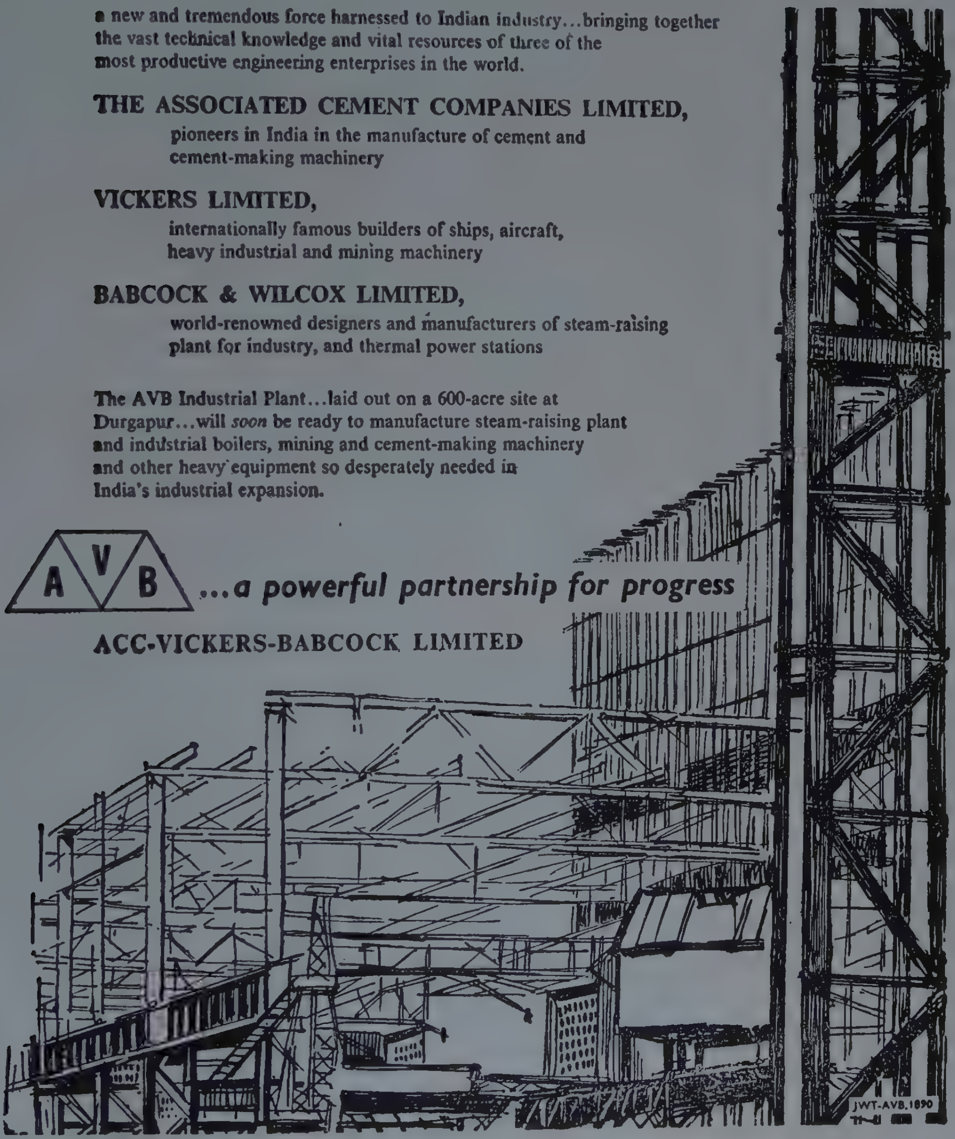

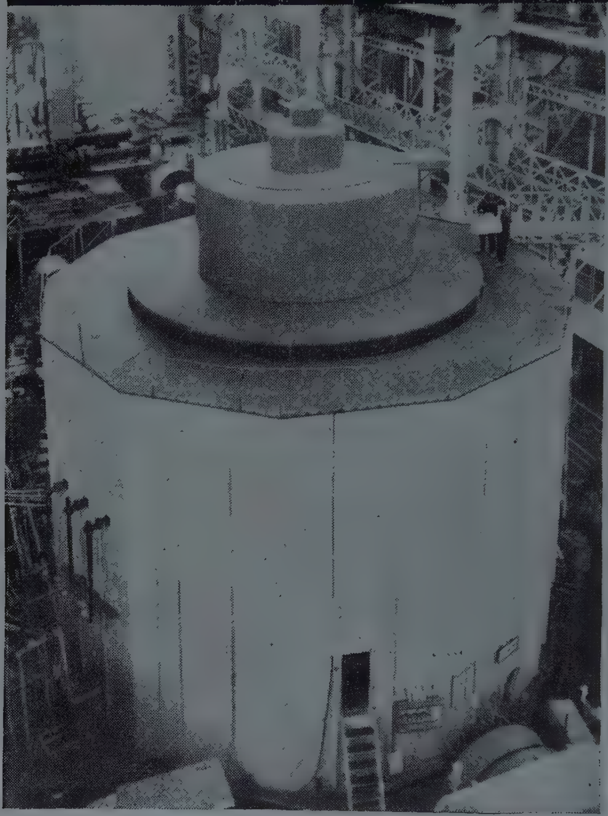

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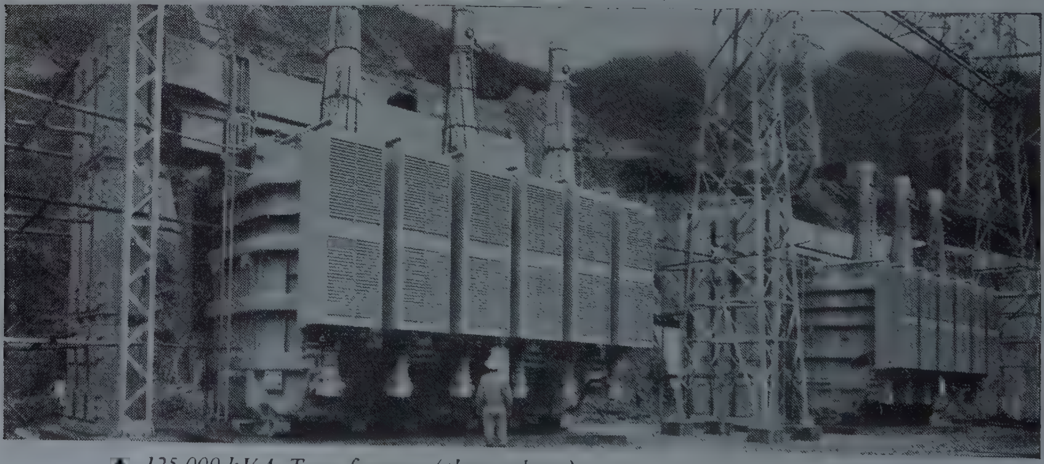

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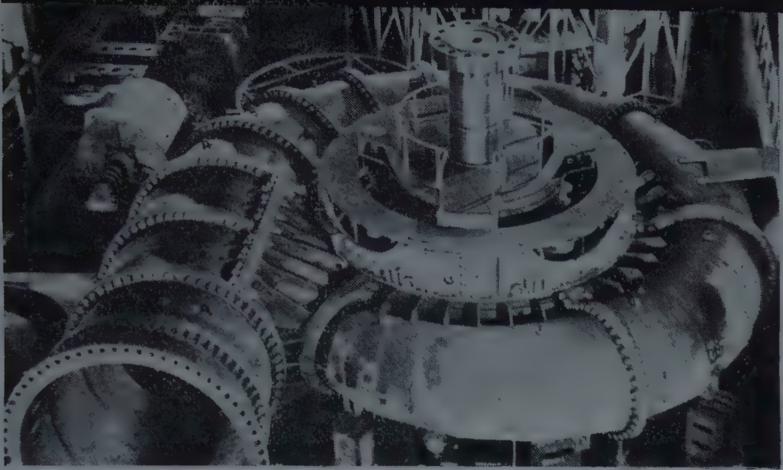
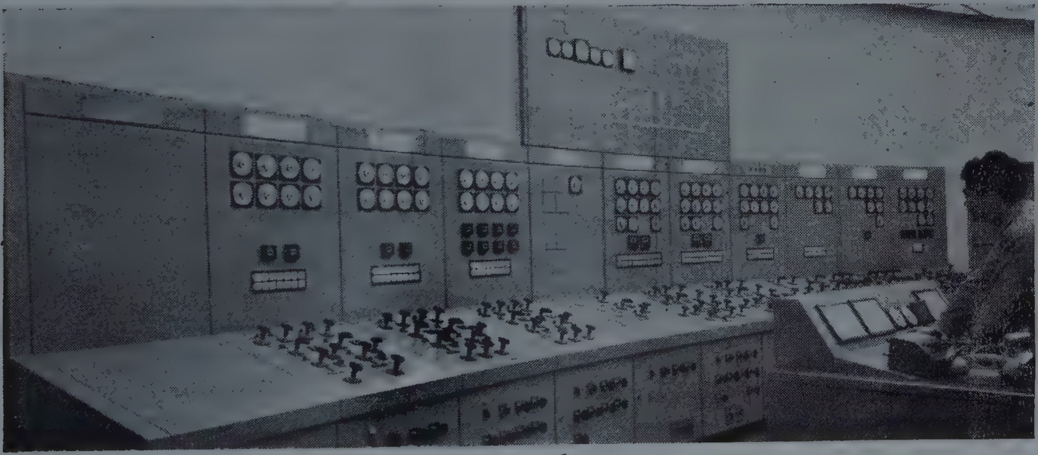


◀ *137,500 kw Turbine*

diameter of 3.7m and the main shaft a diameter of 95cm. The spiral casing, which was constructed in 13 sections to facilitate transportation to the site, has an inlet diameter of 3.35m and an outer diameter of 11.2m. The generator presents a high-torsoed appearance as shown in the photograph, having been so designed in consideration of the comparatively high speed. Since the generator was designed for a rated voltage of 16,500 volts and, in this respect, represents the first such attempt in Japan, particular care was taken in the corona-shielding and impulse resistance of the stator winding.

The generator is rated at 60 cycles, 225rpm and 0.9 power factor but is also capable of operating at 50 cycles, 187.5rpm and 1.0 power factor.



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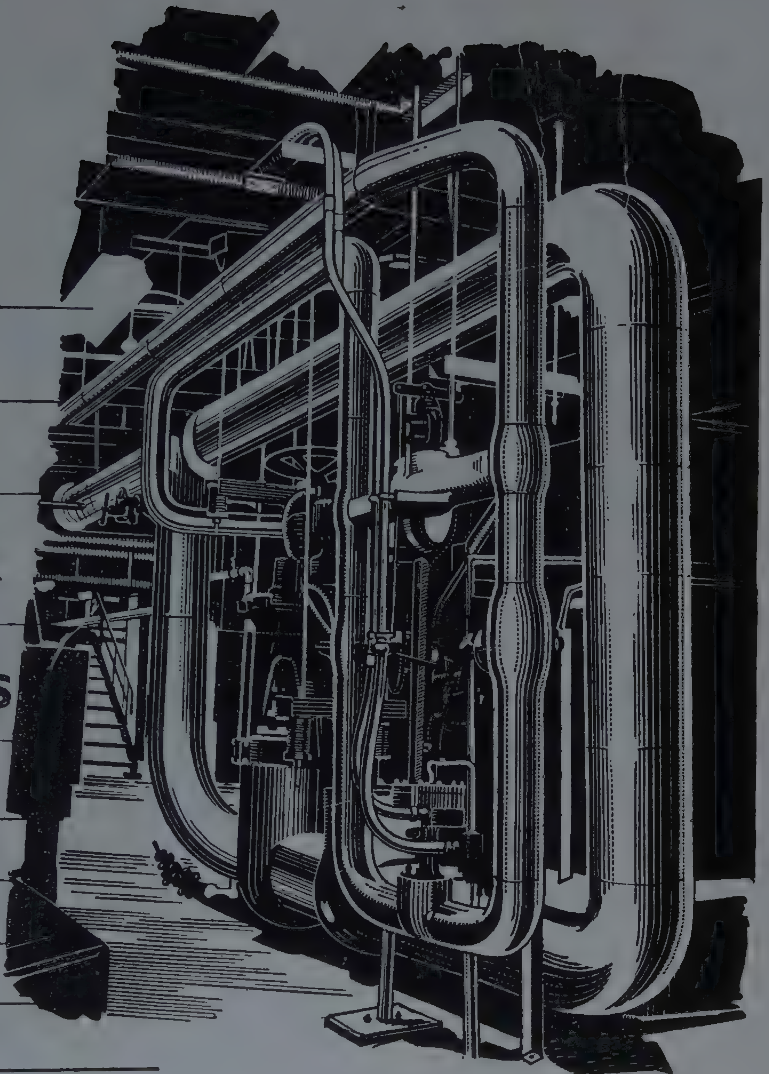

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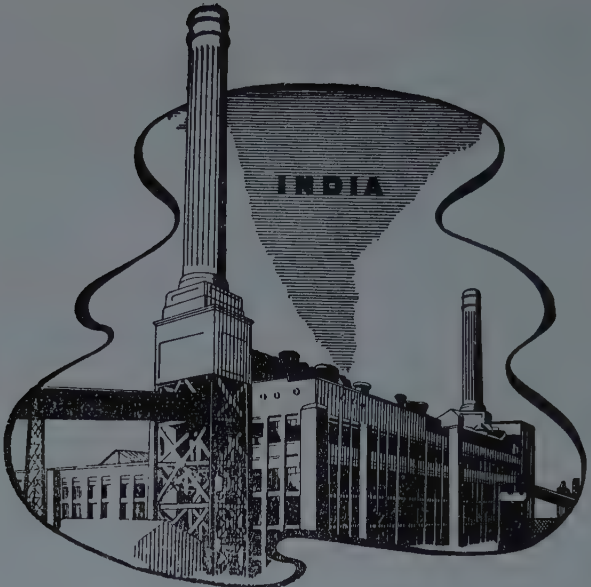

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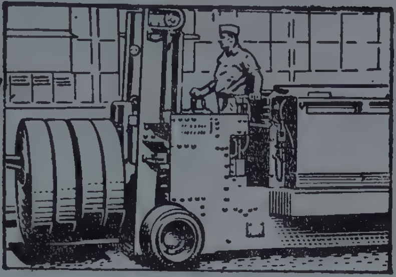

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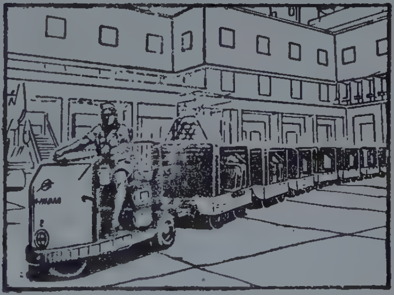

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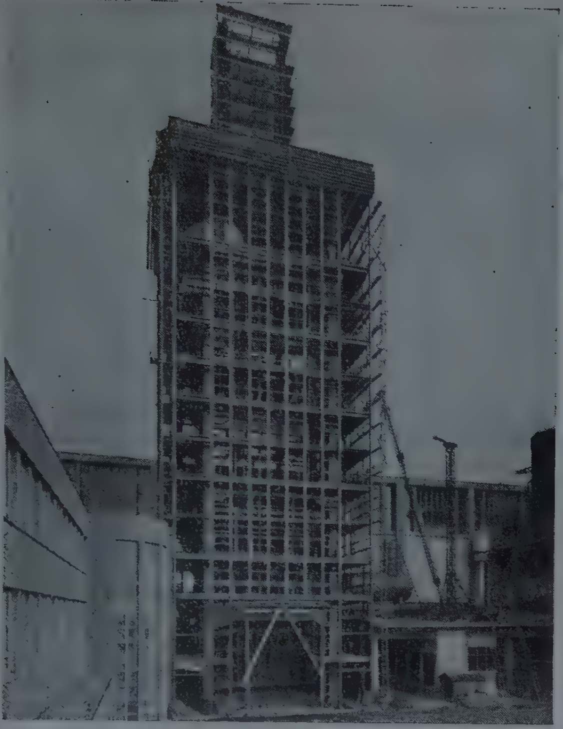
Number of substations	552
Installed transformer capacity ...	39,882 kVA
Transmission lines H.T. ...	858 miles
Distribution lines L.T.	1,141 miles
Agricultural pumpsets	2,440 Nos.
Installed capacity of agricultural pumpsets	8,383 kW
Industrial power services ...	3,523 Nos.
Installed capacity of industrial power	17,749 kW
Towns and villages electrified ...	596 Nos.

Units purchased annually ...	99,242,483
Units sold annually	89,885,499



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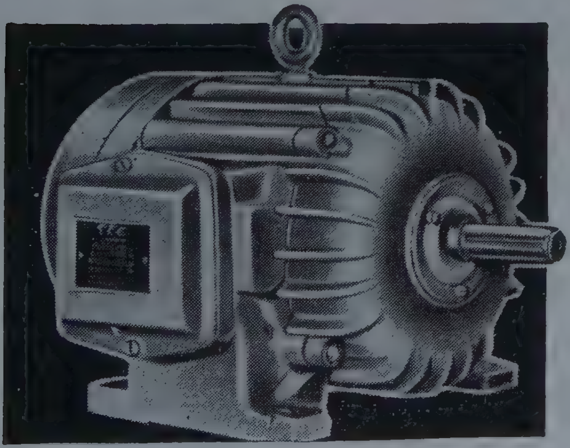

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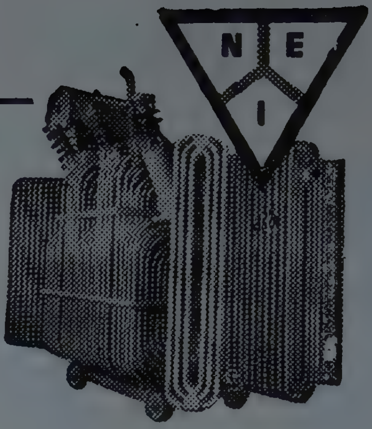

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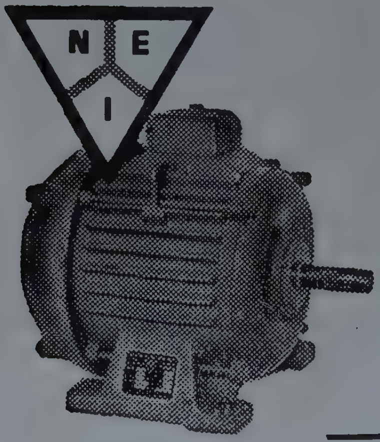

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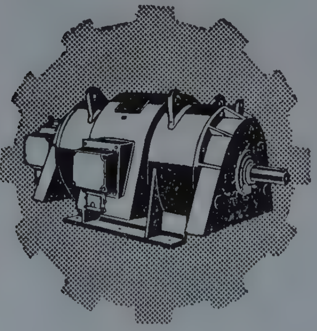

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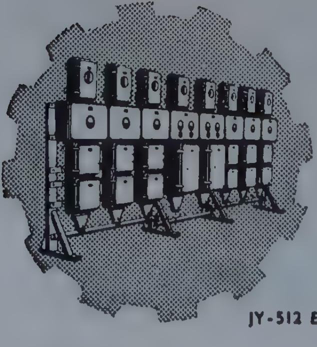

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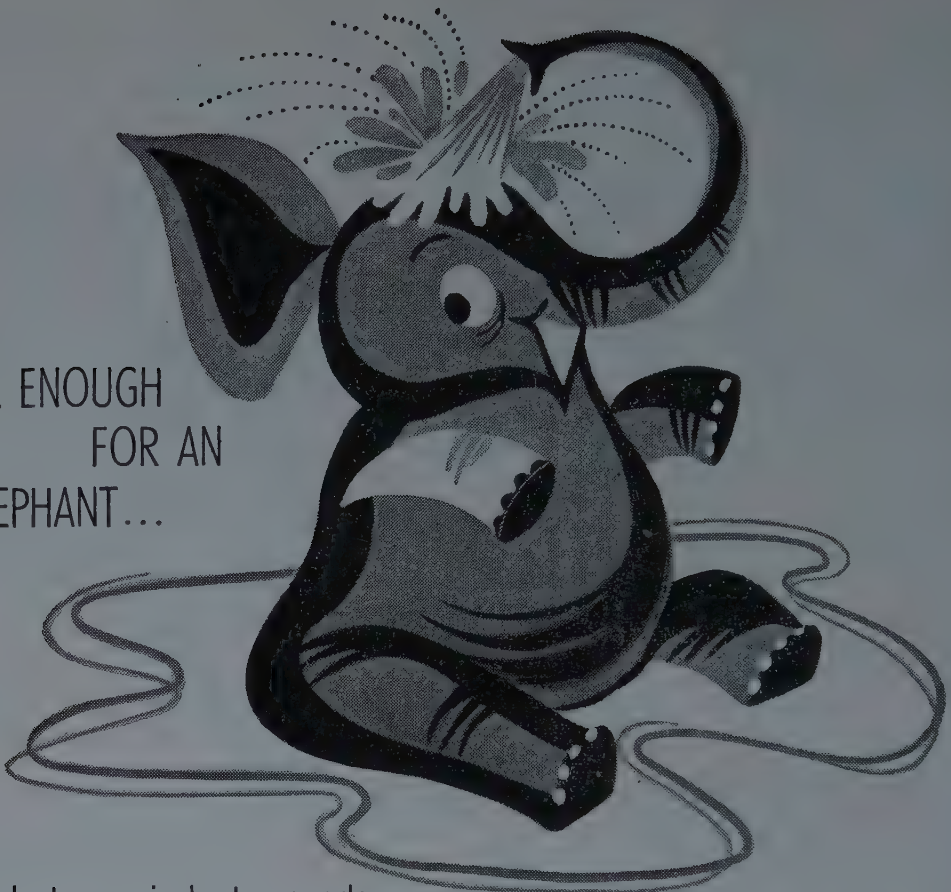

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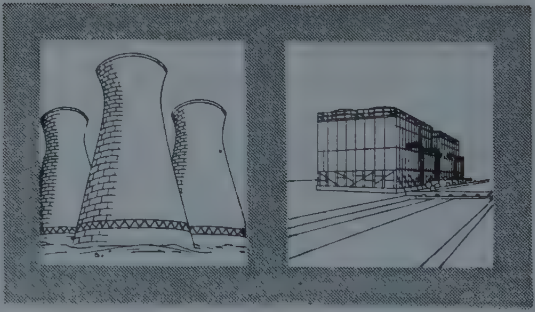

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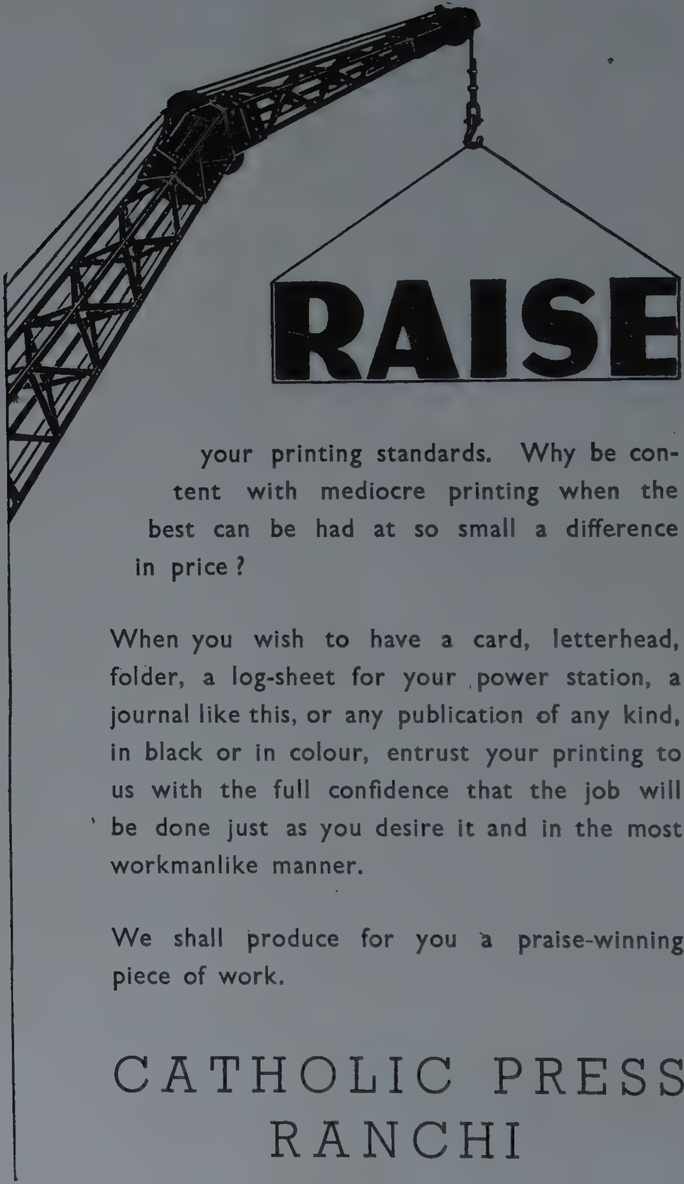

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Dated 21 March 1961

INDEX TO ADVERTISERS

Aberdare Cables Ltd., England	A19
A.C.E.C. India Private Ltd., Bombay	A7
ACC-Vickers-Babcock Ltd., Bombay	A31
Aluminium Industries Ltd., Kundara	A2, 45
Associated Electrical Industries (India) Private Ltd., Calcutta	A23
Batliboi & Co., Bombay	A30
Catholic Press, Ranchi	A48
Dodsal Private Ltd., Bombay	A41
Electrical Machines Corpn. Private Ltd., Calcutta	A26
English Electric Co. Ltd., Calcutta	A11
Ericsson Telephone Sales Corporation AB, New Delhi	A10
Federation of Electricity Undertakings of India, Bombay	A42
General Electric Co. of India Private Ltd., Calcutta	A39
Hitachi Ltd., Tokyo	A32-33
I.A.E.C. (Bombay) Private Ltd., Bombay	A8
Indian Cable Co. Ltd., Calcutta	A12
Indian Iron & Steel Co. Ltd., Burnpur	A6
Industrial Gases Ltd., Calcutta	A50
International Combustion (India) Private Ltd., Calcutta	A28
Johnson & Phillips Ltd., Bombay	A27
John Thompson (India) Private Ltd., Calcutta	A36
Jyoti Calor-Emag Ltd., Baroda	A44
Larsen & Toubro Ltd., Bombay	A4, 14, 21, 25, 34, 46
Martin Burn Ltd., Calcutta	A44
Motwane Private Ltd., Bombay	A17, 43
National Electrical Industries Ltd., Bombay	A40
National Insulated Cable Co. of India Ltd., Calcutta	A22
Nippon Gaishi Kaisha Ltd., Japan	A51
Scientific Instrument Co. Ltd., Allahabad	A13
Siemens Engineering & Manufacturing Co. of India Private Ltd., Bombay	A24
Simmering-Garz-Pauker A.G., Austria	A39
SKF Ball Bearing Co. Private Ltd., Bombay	A29
South Madras Electric Supply Corpn. Ltd., Tiruchirapalli	A38
Standard Batteries Ltd., Bombay	A37
Steam & Mining Equipment (India) Private Ltd., Calcutta	A20
Stewarts & Lloyds of India Private Ltd., Calcutta	A35
Technoexport, Czechoslovakia	A9
Union Carbide India Ltd., Calcutta	A18
Voltas Ltd., Bombay	A52
Walther & Cie, A.G., Germany	A16
William Jacks & Co. Ltd., Calcutta	A15

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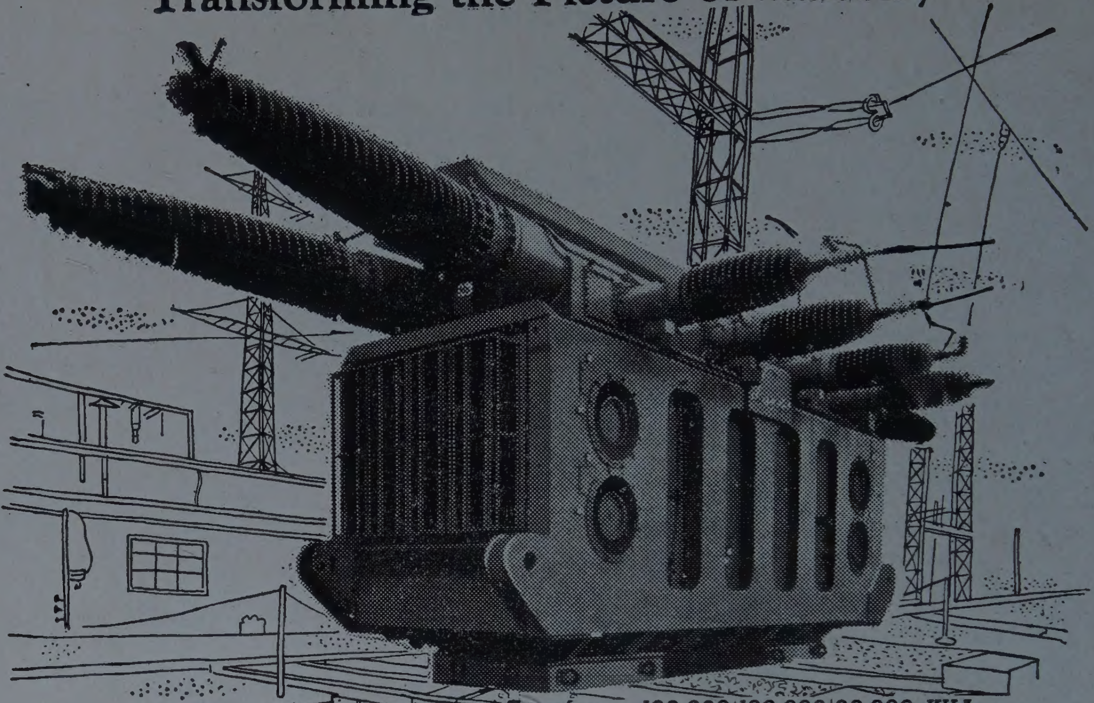

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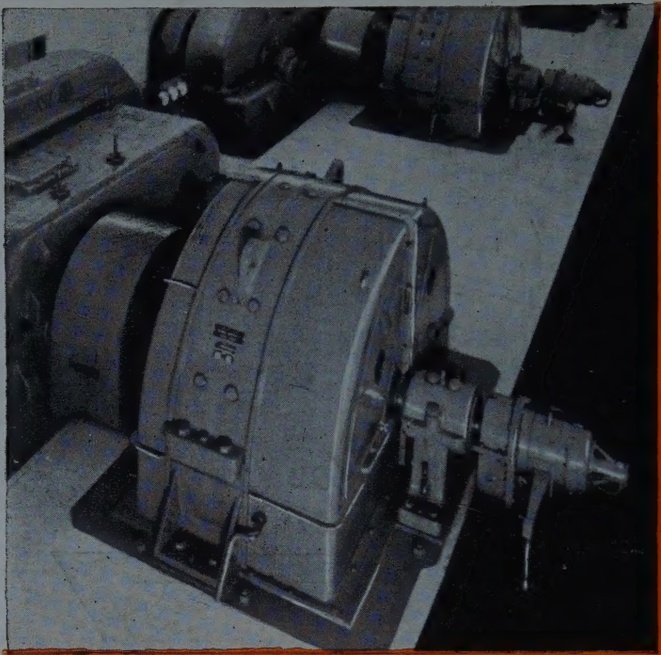

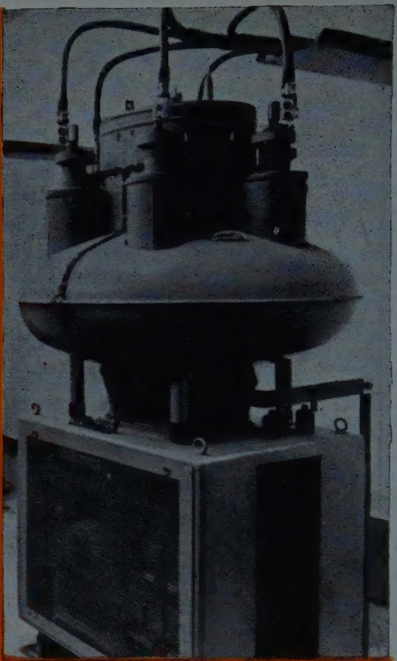

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